(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 January 2003 (23.01.2003)

PCT

(10) International Publication Number
WO 03/007372 A2

(51) International Patent Classification[7]: H01L 23/473, G06F 1/20

(21) International Application Number: PCT/CA02/01078

(22) International Filing Date: 15 July 2002 (15.07.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2,352,997 13 July 2001 (13.07.2001) CA
10/025,846 26 December 2001 (26.12.2001) US

(71) Applicant *(for all designated States except US)*: **COOLIT SYSTEMS INC.** [CA/CA]; 10820 Hidden Valley Drive NW, Calgary, Alberta T3A 5H2 (CA).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **SCOTT, Alexander, Robin, Walter** [CA/CA]; 10820 Hidden Valley Drive NW, Calgary, Alberta T3A 5H2 (CA).

(74) Agent: **BENNETT JONES LLP**; Caldwell, Roseann, B., 4500 Bankers Hall East, 855 - 2nd Street SW, Calgary, Alberta T2P 4K7 (CA).

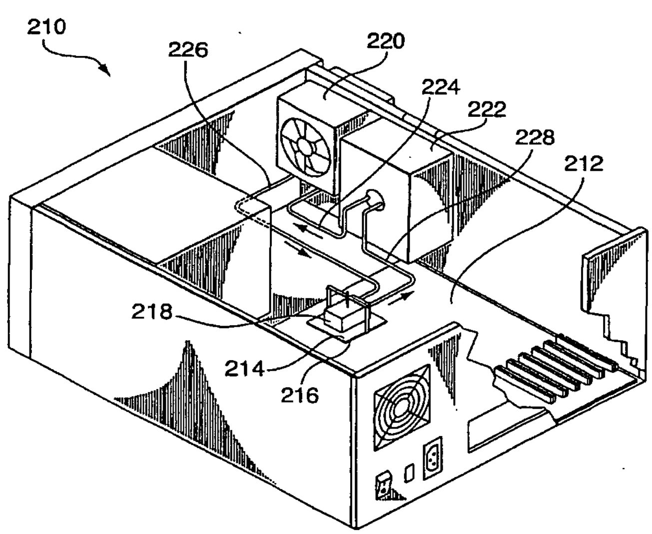
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

[Continued on next page]

(54) Title: COMPUTER COOLING APPARATUS



(57) Abstract: An apparatus for cooling an electronic device that includes a fluid heat exchanger, a chiller, and a pump. The fluid heat exchanger transfers heat from a hot portion of the surface of the electronic device to a fluid and has a body through which the fluid may be circulated. The body has a protrusion having a first surface that may be thermally coupled to the hot portion such that the surface of the body is sufficiently distant from the surface of the electronic device that sufficient ambient air may circulate therebetween so as to substantially prevent condensation from forming on the surface of the electronic device and from forming on and dripping from the heat exchanger when the fluid is cooled to at least the dew point of the ambient air and circulated through the body. A heat-conducting path is provided from the first surface to a region of the body that is thermally coupled to the fluid when the fluid is circulated through the body. The chiller circulates the fluid through a chiller and the fluid heat exchanger.

WO 03/007372 A2

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

COMPUTER COOLING APPARATUS

Field of the Invention

The invention relates to the field of cooling electronic devices and, in particular, to using circulating fluids to cool microprocessors, graphics processors, and other computer components.

Background

Microprocessor dies typically used in personal computers are packaged in ceramic packages that have a lower surface provided with a large number of electrical contacts (e.g., pins) for connection to a socket mounted to a circuit board of a personal computer and an upper surface for thermal coupling to a heat sink. In the following description, a die and its package are referred to collectively as a microprocessor.

Elevation views of typical designs for heat sinks suggested by Intel Corporation for its Pentium® III microprocessor are shown in Figures 1A and 1B.

In Figure 1A, a passive heat sink indicated generally by reference numeral 110 is shown. The passive heat sink 110 comprises a thermal plate 112 from the upper surface of which a number of fins, one of which is indicated by reference numeral 114, protrude perpendicularly. The passive heat sink 110 is shown in Figure 1A installed upon a microprocessor generally indicated by reference numeral 118. The microprocessor 118 is comprised of a die 116 and a package 120. The die 116 protrudes from the upper surface of the package 120. The lower surface of the package 120 is plugged into a socket 122, which is in turn mounted on a circuit board (not shown). The passive heat sink 110 is installed by bringing the lower surface of the thermal plate 112 into contact with the exposed surface of the die 116. When installed and operated as recommended by the manufacturer, ambient airflow passes between the fins in the direction shown by an arrow 124 in Figure 1A.

BNSDOCID: <WO 03007372A2 I >

In Figure 1B, an active heat sink, indicated generally by reference numeral 126, is shown. The active heat sink 126 comprises a thermal plate 128 from the upper surface of which a number of fins 130 protrude perpendicularly. A fan 132 is mounted above the fins 130. The active heat sink 126 is shown in Figure 1B installed upon a microprocessor, generally indicated by reference numeral 136, which is comprised of a die 134 and a package 138. The die 134 protrudes from the upper surface of the package 138. The lower surface of the package 138 is plugged into a socket 140, which is in turn mounted on a circuit board (not shown). The active heat sink 126 is installed by bringing the lower surface of the thermal plate 128 into contact with the exposed surface of the die 134. When installed and operated as recommended by the manufacturer, ambient air is forced between the fins 130 in the direction shown by an arrow 142 in Figure 1B.

A difficulty with the cooling provided by the heat sinks shown in Figures 1A and 1B is that at best the temperature of the thermal plates 112, 128 can only approach the ambient air temperature. If the microprocessor 118, 136 is operated at a high enough frequency, the die 116, 134 can become so hot that it is difficult to maintain a safe operating temperature at the die 116, 134 using air cooling in the manner shown in Figures 1A and 1B.

Liquid cooling, which is inherently more efficient due to the greater heat capacity of liquids, has been proposed for situations in which air cooling in the manner illustrated in Figures 1A and 1B is inadequate. In a typical liquid cooling system, such as that illustrated in Figure 1C, a heat conductive block 144 having internal passages or a cavity (not shown) replaces the thermal plate 128 in Figure 1B. The block 144 has an inlet and an outlet, one of which is visible and indicated by reference numeral 146 in Figure 1C. Liquid is pumped into the block 144 through the inlet and passes out of the block 144 through the outlet to a radiator or chiller (not shown) located at some distance from the block 144. The block 144 is shown in Figure 1C installed upon a microprocessor generally indicated by reference numeral 148, which is comprised of a die 150 and a package 152. The die 150 protrudes from the upper surface of the package 152. The lower surface of the package 152 is

BNSDOCID: <WO 03007372A2 I >

plugged into a socket 154, which is in turn mounted on a circuit board (not shown). The block 144 is installed by bringing its lower surface into contact with the exposed surface of the die 150.

In all liquid cooling systems known to the inventor, only a small portion of the lower surface of the block 144 comes into contact with the die 150. Since the die 150 protrudes above the upper surface of the package 152, a gap 156 remains between the upper surface of the package 152 and the block 144. If the gap 156 is not filled with insulation and sealed, convective and radiative heat transfer from the package 152 to the block 144 may occur. This will have no serious consequences so long as the block 144 is not cooled below the dew point of the air in the gap 156. If the liquid pumped through block 144 is only cooled by a radiator, then that liquid and consequently the block 144, can only approach the ambient air temperature. However, if a chiller is used to cool the liquid, then the temperature of the block 144 can decrease below the ambient air temperature, which may allow condensation to form on the package 152 or the block 144. Such condensation, if not removed, can cause electrical shorts, which may possibly destroy the microprocessor 148.

Current solutions to the condensation problem referred to above include (1) controlling the chiller so that the temperature of the block 144 does not decrease below the dew point of the air in the gap 156 or (2) providing sufficient insulation and sealing material to prevent condensation from forming or to at least prevent any condensation that does form from reaching critical portions of the microprocessor 148 or surrounding circuit elements. Placing a lower limit on the temperature of the chiller limits the amount of heat that can effectively be removed from the microprocessor 148 without using bulky components. Further, the operating temperature of the microprocessor 148 can only approach the temperature of the block 144; operation at lower temperatures may be desirable in many circumstances. Alternatively, if insulation and sealing is used, trained technicians must do the installation properly if the installation is to be effective. If the insulation or seals fail, condensation can occur and cause catastrophic failure of the personal computer. A simpler, more reliable solution to the condensation problem is needed.

BNSDOCID: <WO 03007372A2 I >

Summary

In one aspect the invention provides a heat exchanger for extracting heat from an electronic device, such as a microprocessor, through a hot portion of the surface of the electronic device. The heat exchanger has a body through which a fluid may be circulated. The body has a protrusion having a first surface that may be thermally coupled to the hot portion of the electronic device. A heat-conducting path is provided from the first surface to a region of the body that is thermally coupled to the fluid when the fluid is circulated through the body. Preferably, when the first surface is thermally coupled to the hot portion, the surface of the body is sufficiently distant from the surface of said electronic device other than the hot portion that sufficient ambient air may circulate therebetween so as to substantially prevent condensation from forming on the surface of said electronic device and from forming on and dripping from the heat exchanger when said fluid is cooled to at least the dew point of the ambient air and circulated through the body.

In another aspect the invention provides a heat exchanger for extracting heat from an electronic device through a hot portion of the surface of the electronic device. The heat exchanger includes a body that may be cooled by a circulating fluid and a conduit for circulating the cooling fluid. The body has a first surface that may be thermally coupled to the hot portion of the electronic device and a heat-conducting path from the first surface to a portion of the body that is thermally coupled to the fluid when the fluid is circulated. Preferably, when the first surface is thermally coupled to the hot portion, the surface of the body other than the first surface and the conduit are sufficiently distant from the surface of the electronic device other than the hot portion that sufficient ambient air may circulate therebetween so as to substantially prevent condensation from forming on the surface of the electronic device and from forming on and dripping from the heat exchanger when the fluid is cooled to at least the dew point of the ambient air and circulated.

INSDOCID <WO 0300737242 I >

In another aspect the invention provides an apparatus for extracting heat from an electronic device, such as a microprocessor. The apparatus includes a first fluid heat exchanger for transferring heat from a hot portion of the surface of the electronic device to a fluid, a chiller for chilling the fluid, and a pump for circulating said fluid through said chiller and said first fluid heat exchanger. The first fluid heat exchanger includes a body through which the fluid may be circulated. The body has a protrusion having a first surface that may be thermally coupled to the hot portion. Preferably, when the first surface is thermally coupled to the hot portion, the surface of the body is sufficiently distant from the surface of the electronic device other than the hot portion that sufficient ambient air may circulate therebetween so as to substantially prevent condensation from forming on the surface of said electronic device and from forming on and dripping from the heat exchanger when the fluid is cooled to at least the dew point of the ambient air and circulated through the body. A heat-conducting path is provided from the first surface to a region of the body that is thermally coupled to the fluid when the fluid is circulated through the body.

Brief Description of the Drawings

Figure 1A is a schematic elevation view of a conventional passive heat sink installed on a microprocessor.

Figure 1B is a schematic elevation view of a conventional active heat sink installed on a microprocessor.

Figure 1C is a schematic elevation view of a conventional liquid-cooled heat sink installed on a microprocessor.

Figure 2A is a schematic pictorial view of a partially assembled desktop personal computer with an embodiment of the cooling apparatus described herein installed. Many of the conventional components of the desktop personal computer that are not relevant to the cooling apparatus are omitted.

BNSDOCID: <WO 03007372A2 I >

Figure 2B is a schematic pictorial view of a partially assembled tower-case personal computer with an embodiment of the cooling apparatus described herein installed. Many of the conventional components of the desktop personal computer that are not relevant to the cooling apparatus are omitted.

Figure 3A is a schematic elevation view of a portion of the desktop personal computer of Figure 2A showing a fluid heat exchanger in accordance with the present invention coupled to the CPU microprocessor of the computer.

Figure 3B is a schematic elevation view of a portion of the tower-case personal computer of Figure 2B showing a fluid heat exchanger in accordance with the present invention coupled to the CPU microprocessor of the computer.

Figures 3C - 3F are schematic elevation views of a series of variant fluid heat exchangers.

Figure 3G is a schematic elevation view of a variant fluid heat exchanger having an external cooling conduit.

Figure 3H is a schematic cross-sectional view of the fluid heat exchanger shown in Figure 3G taken along line 3H-3H of Figure 3G.

Figure 4A is a schematic exploded isometric view of the fluid heat exchanger shown in Figure 3A.

Figures 4B, 4C, and 4D are schematic cross-sectional views of the fluid heat exchanger of Figure 4A taken along lines 4B-4B, 4C-4C, and 4D-4D of Figure 4A, respectively.

Figure 4E is a schematic pictorial view of the fluid heat exchanger of Figure 3A showing the internal fluid flow pattern.

Figure 5A is a schematic partially exploded isometric view of the fluid heat exchanger of Figure 3B.

Figure 5B is a schematic cross-section of the fluid heat exchanger of Figure 5A taken along line 5B-5B of Figure 5A.

Figure 6A is a schematic isometric view of a molded or cast one-piece fluid heat exchanger in accordance with the present invention.

Figure 6B is a schematic elevation view of the fluid heat exchanger of Figure 6A.

Figure 6C is a schematic cross-sectional view of the fluid heat exchanger of Figure 6A taken along line 6C-6C of Figure 6B.

Figures 6D, 6E, 6F, 6G, 6H, 6I, 6J, and 6K are schematic cross-sections of the fluid heat exchanger of Figure 6A taken along lines 6D-6D, 6E-6E, 6F-6F, 6G-6G, 6H-6H, 6I-6I, 6J-6J, and 6K-6K of Figure 6C, respectively. The barbs and protrusion are not shown.

Figure 7A is a schematic isometric view of another fluid heat exchanger in accordance with the present invention.

Figures 7B, 7C and 7D are sectional views of the fluid heat exchanger of Figure 7A taken along lines 7B-7B, 7C-7C and 7D-7D, respectively. Figures 7B and 7C show views with a clamping wire removed.

Figure 8A is a schematic elevation view of the pump/tank module of the cooling apparatus of Figure 2A and 2B.

Figure 8B is a schematic side elevation view of a molded pump/tank module that could be included in the cooling apparatus of Figures 2A and 2B.

BNSDOCID: <WO 03007372A2 I >

Figure 8C is a schematic end elevation view of the pump/tank module of Figure 8B.

Figure 8D is a schematic internal side elevation view of the pump/tank module of Figure 8B.

Figure 8E is a side elevation view in exploded configuration of another pump module that could be used in the cooling apparatus of Figures 2A and 2B. Two housing portions of the pump module are shown in section to facilitate understanding.

Figure 8F is a side elevation view in assembled configuration of the pump module of Figure 8E.

Figure 9A is a schematic end elevation view of a copper-finned chiller module in accordance with the invention, with the fan removed. The view is taken in the direction of airflow when chiller module is in operation.

Figure 9B is a schematic longitudinal section of the chiller module of Figure 9A taken along line 9-9 of Figure 9A.

Figure 10 is a schematic end elevation view of an aluminum-finned chiller module having four extruded fin sections, in accordance with the invention. The view is taken with the fan removed and in the direction of airflow when chiller module is in operation.

Figure 11 is a longitudinal cross-section of the chiller module of Figure 10 taken along line 11-11 of Figure 10.

Figure 12 is a side elevation view of the chiller module of Figure 10 with the housing removed.

Figure 13 is a cross-section of one of the four extruded fin sections of the chiller module of Figure 10.

Figure 14 is a schematic end elevation view of an aluminum-finned chiller module having two extruded fin sections, in accordance with the invention. The view is taken with the fan removed and in the direction of airflow when chiller module is in operation.

Figure 15 is a longitudinal cross-section of the chiller module of Figure 14 taken along line 15-15 of Figure 14.

Figure 16 is a cross-section of one of the two extruded fin sections of the chiller module of Figure 14.

Figure 17 is a sectional view through another aluminum-finned chiller module according to the present invention.

Figure 18 is a partially exploded isometric view of a bored fluid heat exchanger for use in the chiller modules of Figures 9, 10, 14 and 17.

Figure 19A is a schematic isometric view of a molded or cast fluid one-piece heat exchanger for use in the chiller modules of Figures 9, 10, 14 and 17.

Figure 19B is a schematic elevation view of the fluid heat exchanger of Figure 19A.

Figure 19C is a schematic cross-sectional view of the fluid heat exchanger of Figure 19A taken along line 19C-19C of Figure 19B.

Figures 19D, 19E, 19F, 19G, 19H, 19I and 19J are schematic cross-sections of the fluid heat exchanger of Figure 19A taken along lines 19D-19D, 19E-19E, 19F-19F, 19G-19G, 19H-19H, 19I-19I and 19J-19J of Figure 19C, respectively. The barbs are not shown.

BNSDOCID: <WO 03007372A2 I >

Figure 20A is a sectional view through another heat exchanger useful in the chiller modules of Figures 9, 10, 14 and 17.

Figures 20B and 20C are schematic figures showing flow patterns through a heat exchanger of Figure 20A.

Figure 21A is a schematic plan view of a molded retainer for retaining a fluid heat exchanger coupled to a CPU microprocessor in accordance with the invention.

Figure 21B is a schematic front elevation view of the retainer of Figure 21A.

Figure 21C is a schematic side elevation view of the retainer of Figure 21A.

Detailed Description

Two embodiments of the present invention are shown in Figures 2A and 2B as they would appear when installed in two typical forms of desktop personal computer ("PC"), the PCs generally indicated by reference numerals 210 and 250, respectively. In Figure 2A, the PC 210 is a desktop-type PC, while in Figure 2B, the PC 250 is a tower-type PC. In Figures 2A and 2B, the PC 210, 250 is shown with its case cover and power supply removed so that a cooling apparatus that is an embodiment of the present invention can be seen. Each PC 210, 250 has a motherboard 212, 252 together with a CPU microprocessor 214, 254 mounted in a socket 216, 256 as shown schematically in Figures 2A and 2B. In each case, the socket 216, 256 is mounted on the motherboard 212, 252. Other conventional components are omitted.

As illustrated in Figures 2A and 2B, each cooling apparatus is comprised of three modules: a heat exchanger 218, 258 mounted in contact with the CPU microprocessor 214, 254; a chiller module 220, 260; and a pump module 222, 262. Each heat exchanger 218, 258 is mounted so as to be thermally coupled to a CPU microprocessor 214, 254 and replaces a conventional heat sink such as those shown in Figures 1A and 1B. The details of the manner in which the heat exchangers 218, 258

are mounted are described below. The chiller module 220, 260 and the pump module 222, 262 are mounted to the case of the PC 210, 250 and connected together by a first section of tubing 224, 264. The chiller module 220, 260 is connected to the heat exchanger 218, 258 by a second section of tubing 226, 266. The heat exchanger 218, 258 is connected to the pump module 222, 262 by a third section of tubing 228, 268. In operation, fluid is pumped from the pump module 222, 262 through the chiller module 220, 260, then through the heat exchanger 218, 258, and finally returns to the pump module 222, 262. When the cooling apparatus is operating, chilled fluid passes through the heat exchanger 218, 258 so as to extract heat produced by the microprocessor 214, 254.

Figures 3A and 3B provide more detailed views of the heat exchangers 218, 258 as mounted on the microprocessors 214, 254 in Figures 2A and 2B. The upright heat exchanger 218 of Figure 2A differs in several details from the horizontal heat exchanger 258 of Figure 2B. Hence, each is described separately.

In Figure 3A, the microprocessor 214 can be seen to be of the conventional flip-chip type comprising a die 310 mounted in a mounting package 312. The die 310 extends above the surrounding surface 313 of the mounting package 312 and provides a non-active surface 311 that is generally parallel to the surrounding surface 313. In this type of mounting, no thermal plate is provided as part of the microprocessor 214, it being intended that a heat sink will be installed directly in contact with the non-active surface 311. "Non-active surface" as used herein refers to the face of a die that does not have electrical contacts and that is normally exposed to cooling air flow or placed in contact with a heat sink or other means from removing heat from the die 310.

As illustrated in Figure 3A, the upright heat exchanger 218 is comprised of a cuboid body 314 of a heat-conducting material such as copper, aluminum, or plastic that has a cuboid protrusion 316 extending from its bottom face 318. Optionally, the bottom face of the protrusion 316 may be a thin silver cap 319. As will be discussed in relation to Figures 4A – 4E, the body 314 contains internal passages and chambers

BNSDOCID: <WO 03007372A2 I >

(not shown in Figure 3A) through which a fluid may be circulated. The protrusion 316 ends in a face 320 (sometimes referred to as a surface herein), which should preferably be dimensionally substantially congruent with the non-active surface 311 of the die 310. Some of the advantages of the invention are reduced if the face 320 is not substantially congruent with the non-active surface 311. If the face 320 does not contact the entire non-active surface 311, then the rate at which heat can be transferred is reduced, although if for some reason the die is not uniformly hot, this may be desirable or at least tolerable. On the other hand, if the face 320 is larger than the non-active surface 311, the disadvantages of conventional liquid heat exchangers such as that shown in Figure 1C begin to appear as the difference in size increases. An empirical approach should be used to applying the present invention to a particular microprocessor installation.

While the body 314 and the protrusion 316 are shown as cuboid in the drawings, they may be any convenient shape so long as the body 314, through which fluid is circulated, is separated from the microprocessor 214 by a sufficient distance and a face 320 is provided that is approximately dimensionally congruent with and conforms to the non-active surface 311 of the die 310. Further, in some circumstances the protrusion 316 may be eliminated or reduced to the silver cap 319. For example, in Figures 3C - 3F a sample of some possible body shapes are shown. In those drawings, reference numerals correspond to those in Figure 3A where there are corresponding elements. For example, in Figure 3C, a spherical body 380 having no protrusion is shown; the face 320 is simply a flattened portion of the surface of the body 380. In Figure 3D, an inverted truncated pyramidal body 382 is shown; the face 320 is provided by an optional silver cap 319 that is in effect a small protrusion. In Figure 3E, a columnar body 384 is shown and in Figure 3F, a truncated pyramidal body 386 is shown. In each case, appropriate internal passages (not shown) must be provided to circulate cooling fluid; a fluid inlet fitting 328 and a fluid outlet fitting 330 are shown in each drawing. Further, in Figure 3A, the protrusion 316 could be cylindrical rather than rectangular in cross-section preferably ending in a face 320 that is approximately dimensionally congruent with and conforms to the non-active surface of the die 310.

One goal in designing the upright heat exchanger 218 is to provide means to conduct heat away from the die 310 and then transfer that heat to a fluid circulating through the body 314 of the upright heat exchanger 218. If a protrusion 316 is provided, it should preferably have a cross-sectional area that does not increase rapidly with distance from the die 310 and should be designed to transfer heat as efficiently as possible to the body 314, rather than to dissipate heat itself. Ideally the temperature should drop as little as possible from the non-active surface 311 to the body 314 so as to minimize the possibility of condensation forming on the protrusion 316 if the fluid circulating through the body 314 is chilled below the dew point of the ambient air. In other words, a heat-conducting path must be provided from the protrusion 316 to the circulating fluid. This path may be provided by the material out of which the upright heat exchanger 218 is formed, or by a heat pipe integrated into the upright heat exchanger 218, or by a thermoelectric heat pump placed between the die 310 and the body 314, possibly as a protrusion 316 from the body 314.

Preferably, the protrusion 316 should extend far enough from the microprocessor 214 so that the lower surface 318 of the body 314 is sufficiently distant from the surface 313 of the microprocessor 214 such that sufficient ambient air may circulate in the gap between them so as to substantially prevent condensation from forming on the surface 313 of the microprocessor 214 and from forming on and dripping from the body 314 when fluid is cooled below the dew point of the ambient air and circulated through the body 314. Just how far the fluid should be cooled depends upon how much heat needs to be conducted away from the die 310. The further the fluid is cooled, the more heat can be conducted away using the same sizes for components such as the pump module 222, 262 and the heat exchanger 218, 258. There is therefore an economic advantage in using colder fluid, but at some point the gap between the surface of the body 314 and the surface of the microprocessor 214 will no longer allow sufficient air circulation. Hence the distance that the protrusion 316 extends from the body 314 must be determined empirically based upon the amount of heat needed to be conducted away and the sizes of the components. As noted above, a discrete protrusion may not be needed if the body 314 has a shape that

BNSDOCID: <WO 03007372A2 I >

provides a sufficient gap between the body 314 and the surface of the microprocessor 214. Several examples of this are shown in Figures 3C – 3 G.

The inventor has found that even a small distance between the lower surface 318 of the body 314 and the surface 313 of the microprocessor 214 will allow the fluid to be cooled further than is possible using conventional heat exchangers without sealing and insulation. For example, a distance of approximately 6 mm has been found to be sufficient to allow for cooling current CPU microprocessors using circulating fluid cooled to below the dew point of the ambient air.

It is critical that (1) condensation not be allowed to form on the microprocessor 214 or other components and, (2) if condensation does form on the upright heat exchanger 218, then it does not drip or otherwise run onto the microprocessor 214 or other components. In general, heat transfer from the socket 216, the motherboard 212, or the microprocessor 214 to the body 314 should not be allowed to lower the temperature of any portion of the socket 216, the motherboard 212, or the microprocessor 214 so as to allow condensation to form on them. One way to accomplish this is to keep the gap between the body 314 and the microprocessor 214 sufficiently large that convection cells will not establish themselves in that gap under normal operating conditions so as to cause convective heat transfer. Further, the body 314 should be sufficiently exposed to ambient air flow that if condensation does form on the body 314, it will evaporate without dripping onto the microprocessor 214 or other components.

The upright heat exchanger 218 is held in place so that the face 320 of the protrusion 316 is thermally coupled to the die 310 by a clamping arrangement formed from a plastic bar 322, two stainless steel spring clips 324, and a bolt 326. The spring clips 324 hook under opposite sides of the socket 216 and extend upward to attach to opposite ends of the plastic bar 322. The plastic bar 322 is provided with an opening aligned with the center of the die 310 that is threaded to accept the bolt 326. The upright heat exchanger 218 is installed by placing the face 320 of the protrusion 316, preferably coated with thermal grease, against the non-active surface of the die 310

and then tightening the bolt 326 until the bolt 326 contacts the upright heat exchanger 218. The use of a plastic bar 322 minimizes the possibility that excessive pressure will be applied to the die 310 by tightening the bolt 326, because the plastic bar 322 will break if too much pressure is applied.

As illustrated in Figure 3A, the upright heat exchanger 218 is also provided with a fluid inlet fitting 328 and a fluid outlet fitting 330. When installed in the PC 210 shown in Figure 2A, the tubing indicated by reference numeral 226 is connected to the fluid inlet fitting 328 and the tubing indicated by reference numeral 228 is connected to the fluid outlet fitting 330.

Also illustrated in Figure 3A is a screw-in plug 332 and a nylon washer 334. The top of the body 314 is provided with a threaded filler opening (not shown in Figure 3A), which is threaded to accept the screw-in plug 332. The purpose of the threaded filler opening is discussed below, but when assembled, the nylon washer 334 is placed over the opening and the screw-in plug 332 screwed into the opening to cause the nylon washer 334 to seal the opening. The head of the screw-in plug 332 is indented so as to accept the end of the bolt 326 and align the upright heat exchanger 218 while the bolt 326 is being tightened.

In Figure 3B, the microprocessor 254 can be seen to be of the conventional flip-chip type having a die 350 mounted in a mounting package 352. The die 350 extends above the surrounding surface 353 of the mounting package 352 and provides a non-active surface 351 that is generally parallel to the surrounding surface 353. In this type of mounting, no thermal plate is provided as part of the microprocessor 254, it being intended that a heat sink will be installed directly in contact with the non-active surface 351.

As illustrated in Figure 3B, the horizontal heat exchanger 258 is comprised of a cuboid body 354 of copper that has a cuboid protrusion 356 extending from a face 358 adjacent and parallel to the non-active surface 351 of the die 350. As will be discussed in relation to Figures 5A and 5B, the body 354 contains internal passages

BNSDOCID: <WO 03007372A2 I >

and chambers through which a fluid may be circulated. The protrusion 356 ends in a face 360 (sometimes referred to as a surface herein), which should preferably be dimensionally substantially congruent with and conform to the non-active surface 351 of the die 350. Some of the advantages of the invention are reduced if the face 360 is not substantially congruent with the surface of the die 350. If the face 360 does not contact the entire surface of the die 350, then the rate at which heat can be transferred is reduced, although if for some reason the die 350 is not uniformly hot, this may be desirable or at least tolerable. On the other hand, if the face 360 is larger than the surface of the die 350, the disadvantages of current liquid heat exchangers such as that shown in Figure 1C begin to appear as the difference in size increases. An empirical approach should be used to applying the present invention to a particular microprocessor installation.

The discussion above regarding variant body shapes and design goals for the upright heat exchanger 218 applies as well to the horizontal heat exchanger 258.

The horizontal heat exchanger 258 is held in place so that the face 360 of the protrusion 356 is thermally coupled to the die 350 by a clamping arrangement formed from a plastic bar 362, two stainless steel spring clips 364, and a bolt 366. The spring clips 364 hook under opposite sides of the socket 256 and extend outward to attach to opposite ends of the plastic bar 362. The plastic bar 362 is provided with an opening aligned with the center of the die 350 and threaded to accept the bolt 366. The horizontal heat exchanger 258 is installed by placing the face 360 of the protrusion 356, preferably coated with thermal grease, against the non-active surface of the die 350 and then tightening the bolt 366 until the bolt 366 contacts the horizontal heat exchanger 258. The face of the body 354 may be indented so as to accept the end of the bolt 366 and align the horizontal heat exchanger 258 while the bolt 366 is being tightened. The use of plastic minimizes the possibility that excessive pressure will be applied to the die 350 by tightening the bolt 366, as the plastic bar 362 will break if too much pressure is applied.

The horizontal heat exchanger 258 is also provided with a fluid outlet fitting 370 and a fluid inlet fitting 368, which is not visible in Figure 3B as it is behind fluid outlet fitting 370 in the view provided in Figure 3B (see Figure 5A). When the horizontal heat exchanger 258 is installed in a PC 250, the tubing indicated by reference numeral 266 is connected to the fluid inlet fitting 368 and the tubing indicated by reference numeral 228 is connected to fluid outlet fitting 370.

An alternative heat exchanger is shown in Figures 3G and 3H and indicated generally by reference numeral 390. The heat exchanger 390 has a columnar body 392 similar in shape to the columnar body 384 shown in Figure 3E, but with cooling provided by an exterior winding of tubing 394 rather than an internal passage for circulating cooling fluid. The exterior winding of tubing 394 has an inlet 396 and an outlet 398 corresponding to the fluid inlet fitting 328 and the fluid outlet 330 fitting of the upright heat exchanger 218 of Figure 3A, respectively. The same design criteria apply to the combination of the body 392 and the exterior winding of tubing 394 shown in Figures 3G and 3H as apply to the body 314 and the protrusion 316 shown in Figure 3A. Specifically, if that combination 392/394 were used in place of the upright heat exchanger 218 of Figures 2A and 3A, the exterior winding of tubing 394 should preferably be located so as to reduce heat transfer from the socket 216, the motherboard 212, or the microprocessor 214 to the exterior winding of tubing 394 so that the temperature of any portion of the socket 216, motherboard 212, or the microprocessor 214 would not drop to the point at which condensation would form on them. Further, the exterior winding of tubing 394 should be sufficiently exposed to ambient air flow that if condensation does form on the tubing 394, the condensation will evaporate without dripping onto the microprocessor 214 or other components. Design dimensions are best determined empirically.

The body 392 may be either solid, preferably copper, or may be constructed as a heat pipe as shown in Figure 3H. If so, the body 392 may be bored axially through from its bottom 381 to close to its top surface 383 forming a bored out chamber 385. A silver cap 387 may be joined to the bottom 381 as shown in Figure 3G. A filler opening 389 passes from the chamber through the top surface 383. The filler opening

BNSDOCID: <WO 03007372A2 I >

389 is threaded to receive a screw-in plug 391. The body 392 may be used as a heat pipe if the chamber 385 is evacuated, partially filled with a mixture of approximately 50% acetone, 35% isopropyl alcohol, and 15% water, and the screw-in plug 391, fitted with a nylon washer 393, is tightened to compress the nylon washer 393, thereby sealing the chamber 385. It should be noted that the heat pipe configuration illustrated in Figures 3G and 3H is optional; a solid body 392 may also be used.

As illustrated in Figure 4A, the upright heat exchanger 218 is formed from three sections, a central section 410 from which protrudes a protruding portion 412 which together with the silver cap 319 form the protrusion 316 of Figure 3A, an inlet side section 414, and an outlet side section 416. The three sections are bored through in the pattern shown in Figure 4A and Figures 4B, 4C, and 4D. An inlet end cap 418 covers the inlet side section 414 and an outlet end cap 420 covers the outlet side section 416. When in operation, fluid entering the inlet side section 414 through the fluid inlet fitting 328 flows in a generally spiral pattern 610 as shown in Figure 4E and leaves the upright heat exchanger 218 through the fluid outlet fitting 330.

As illustrated in Figure 4C, the central section 410 has an axial bore or chamber 510 that extends from the face 511 of the protruding portion 412 through the central section 410 nearly to the top surface 513 of the central section 410. A threaded filler opening 422 passes from the chamber 510 through the top surface of the central section 410. The threaded filler opening 422 is threaded to receive the screw-in plug 332. When the silver cap 319 is joined to the lower face 511 of the protruding portion 412 and the screw-in plug 332 tightened to compress the nylon washer 334, the chamber 510 is sealed and may be used as a heat pipe if evacuated and partially filled with a mixture of approximately 50% acetone, 35% isopropyl alcohol, and 15% water.

Figure 5A and Figure 5B illustrate the structure of the horizontal heat exchanger 258 in more detail. The horizontal heat exchanger 258 does not include a heat pipe such as that provided by the chamber 510 in the upright heat exchanger 218, nor does it include a silver cap 319. It comprises a central block 450 bored through

by nine parallel bores that are laterally connected in the manner shown in Figure 5B to form a passage from the fluid inlet fitting 368 to the fluid outlet fitting 370. End caps 452, 454 cover the faces of the central block 450 through which the central block 450 is bored. The end cap indicated by reference numeral 454 covers the face of the central block 450 closest to the die 350. A protrusion 356 is attached to the outer face of end cap 454. The end cap indicated by reference numeral 452 covers the other face of the central block 450 and may have a small indentation on its outer face to assist in aligning horizontal heat exchanger 258 during installation.

While the upright heat exchanger 218 and the horizontal heat exchanger 258 have been shown in the drawings and described as intended for installation in an upright and a horizontal orientation, respectively, those skilled in the art will understand that the horizontal heat exchanger 258 could be installed in an upright orientation and the upright heat exchanger 218 could be installed in a horizontal orientation. However, in the case of the upright heat exchanger 218, suitable wicking (not shown) would then have to be provided in the heat pipe chamber 510, as gravity would not cause condensed liquid to flow back toward the protrusion 412. The heat pipe chamber 510 and more elaborate construction of the upright heat exchanger 218 may not be warranted in all cases. Hence the designer may wish to use the horizontal heat exchanger 258 wherever a simple, less expensive heat exchanger is desired, in both horizontal and upright orientations.

In both the upright heat exchanger 218 and the horizontal heat exchanger 258, a passage provided for the circulation of a fluid is comprised of a series of cylindrical chambers connected by constrictions. For example, in Figure 5B fluid entering the horizontal heat exchanger 258 through fluid inlet fitting 368 passes through nine chambers 451, 453, 456, 458, 460, 462, 464, 466, 468 before leaving through fluid outlet fitting 370. Each pair of successive chambers is connected by a constriction. The constrictions in Figure 5B are indicated by reference numerals 470, 472, 474, 476, 478, 480, 482, and 484. For example, in Figure 5B constriction 470 connects the first pair of chambers 451, 453. The chambers 451, 453, 456, 458, 460, 462, 464, 466, 468 pass completely through section 450 and may be formed by boring through

BNSDOCID: <WO 03007372A2 I >

solid copper blocks, although casting or other methods may be used depending upon the material used. The constrictions also pass completely through the section 450, so that each of the chambers connected by the constriction has an opening in its interior wall passing into the constriction having a boundary defined by two lines along the interior wall of the chamber that run parallel to the axis of the chamber that are connected by segments of the edges of the circular ends of the chamber. The area of the opening should preferably by approximately equal to the cross-section area of the fluid inlet fitting 368 and the fluid outlet fitting 370.

While the chambers 451, 453, 456, 458, 460, 462, 464, 466, 468 shown in Figure 5B and the chambers shown in Figures 4B and 4D are drawn so that the axes of successive pairs of chambers are spaced apart by a distance that is somewhat greater than the diameter of one chamber, it is also within the scope of the invention to space the axes of successive chambers closer to each other or farther apart. For example, in Figures 4A and 5A, the axes of successive chambers are close enough to each other that the constrictions between successive chambers are formed by the overlapping of the chambers. One method for forming such chambers and constrictions is to bore a block of material so that the center of each bore is closer to the next successive bore than the diameter of the bore.

The inventor has found that the one-piece fluid heater exchanger indicated generally by reference numeral 610 in Figures 6A – 6C is less costly to manufacture than the fluid heat exchangers 218, 258 shown in Figures 3A and 3B and described above and may be used in place of fluid heat exchangers 218, 258 in many applications. However, the same design principles apply. The heat exchanger 610 shown in Figures 6A – 6C is die cast in one piece from an aluminum alloy such as 1106 alloy or 6101 alloy using processes that are known to those skilled in the art. That process is not within the scope of the invention, although the arrangement and shapes of the internal passages are within the scope of the invention. The heat exchanger 610 shown in Figures 6A – 6C might also be formed by molding heat-conducting plastic material.

The heat exchanger 610 shown in Figures 6A, 6B, and 6C comprises a cuboid body 612, a protrusion 614, an inlet barb 616, and an outlet barb 618, all of which are die cast as a unitary structure. The protrusion 614 provided complies with the design guidelines discussed above, extending from the lower face 617 of the body 612 and having a face or surface 619 for coupling thermally to the non-active surface of a die. The perpendicular distance between the plane of the surface 619 and the lower face 617 is approximately 6.25 mm. The four sidewalls of the protrusion 614, the face of one of which is indicated by reference numeral 621, are concave with a radius of curvature of approximately 6.25 mm, resulting in the sidewalls 621 being perpendicular to the plane of the surface 619 at their line of contact with it. The inventor has found that for currently available microprocessors, this perpendicular distance and sidewall design works. However, an empirical approach is recommended if the circulating fluid is chilled to lower temperatures. For example, steeper sidewalls, greater perpendicular distance, or both, may be needed.

As illustrated in Figure 6C, inside the body 612 a passage 620 through which chilled fluid may be circulated is provided. The passage 620 connects the opening in the inlet barb 616 to the opening in the outlet barb 618. The passage 620 comprises a series of nine generally spherical chambers connected by eight cylindrical constrictions. Figures 6D – 6K provide a set of cross-sections showing the shapes and relative diameters of the spherical chambers and cylindrical constrictions. The transitions between the spherical chambers and constrictions are smooth. Because the body 612 and the protrusion 614 are formed as a unitary structure from heat-conducting material, a heat-conducting path is provided from the surface 619 to the material of the body 612 adjacent the passage 620 so that heat may flow from the die to fluid circulated through the passage 620.

Referring to Figures 7A – 7C, another fluid heat exchanger 650 is shown. The illustrated fluid heat exchanger can very effectively conduct heat from a protrusion 652 to the body through which the fluid passes to effect heat exchange. Thus, the fluid heat exchanger of Figures 7 is particularly useful for cooling devices having high heat output or which experience heat spikes during operation, such as a CPU.

BNSDOCID: <WO 03007372A2 I >

Heat exchanger 650 is formed from two main parts including a copper portion 656 and a portion 658 formed of material selected to be conductive but preferably less costly than copper, such as aluminum. Copper portion 656 forms protrusion 652 and is mounted in portion 658 in close contact therewith, as by press fitting, to ensure conduction of heat from portion 656 to portion 658.

The protrusion is formed to comply with the guidelines discussed hereinbefore, extending from the lower face 660 of the body and having a face or surface 662 for coupling thermally to the non-active surface of a die.

Fluid heat exchanger 650 further includes a passage through which chilled fluid may be circulated. The passage connects the opening in an inlet barb 616 to the opening in an outlet barb 618. The passage includes a chamber 668 on each side into which a plurality of heat exchange ribs 670 extend such that fluid passes therethrough as it circulates through the body. Chambers 668 are connected by channels 672.

Fluid heat exchanger 650 can advantageously be formed by modification of an extrusion, which forms portion 658, to include an opening for accepting copper insert portion 656 and channels 672. Chambers 668 can be closed by applying, as by welding or adhering, an external wall 674 about the edges of the chamber. Due to ease of construction, chambers 668 and channels 672 can are formed through portion 658. However, it is to be understood that these passages could extend through copper portion 656, should this be desirable. Other modifications to construction are also within the scope of this invention.

The fluid heat exchanger of Figures 7, as noted previously, can handle significant temperature variations and preferably is formed to have a high output. As such barbs 616, 618, chambers 668 and channels 672 should be selected to handle the appropriate volumes and may be larger than those shown hereinbefore.

Fluid heat exchanger 650 includes an upper surface channel 676, selected to engage a clamping wire 678. Wire 678 is stiff, having resiliency which permits it to

be extended over the heat exchanger 650 and secured by hooked ends 680 onto anchor points on the board. Wire 678 is formed to maintain protrusion 652 in close engagement with the die onto which it is mounted and in the correct orientation. While wire 678 is shown it is to be understood that the wire is separable from the fluid heat exchanger and can be sold separately. In addition, other clamping/mounting devices can be used in place of the wire, as desired.

A pump module 222, 262 that may be constructed from commercially available components is shown in detail in Figure 8A. The pump module 222, 262 generally comprises a conventional submersible 12-volt AC pump 710 installed inside a conventional tank 712. The tank 712 has a screw-on lid 714, an inlet fitting 716, an outlet fitting 718, and a compression fitting 720. The outlet 722 of the pump 712 is connected to the outlet fitting 718 by tubing 724. The inlet 726 of the pump 712 is open to the interior of the tank 712 as is the inlet fitting 716. The power cord 721 of the pump 710 is lead through the compression fitting 720 to a suitable power supply outside the case of the PC 210, 250, or alternatively an inverter (not shown) may be provided inside the case of the PC 210, 250 to provide 12 volt AC from the DC power supply of the PC 210, 250. The tank 712 may be initially filled with fluid by removing the screw-on lid 714. The preferred fluid is 50% propylene glycol and 50% water. The tank 712 should be grounded to reduce the risk of a static electrical charge building up and causing sparking. Preferably this should be accomplished by the use of a tank 712 composed of metalized plastic, although a metal plate connected to the case of the PC 210, 250 may be used.

In Figures 8B, 8C, and 8D, a variant pump module indicated generally by reference numeral 750 is shown that includes a pump having a center-tapped motor winding and an inverter. The inverter is disclosed in a copending, commonly-owned application entitled "Inverter" having US application number 10/016,687, which is incorporated herein by reference. It generally comprises a submersible 20-volt AC pump 752 installed inside a tank 754. The tank 754 has a lid 756, an inlet fitting 757, and an outlet fitting 759. The outlet 758 of the pump 752 is connected to the outlet fitting 759 by heater pipe 760. The inlet 762 of the pump 752 is open to the interior

BNSDOCID: <WO 03007372A2 I >

of the tank 750 as is the inlet fitting 757. A power cord from the DC power supply of the PC 210, 250 may be lead through an access opening 764 to connect to an inverter 766. The tank 754 may be initially filled with fluid by removing the lid 756. The preferred fluid is 50% propylene glycol and 50% water. The tank 754 should be grounded to reduce the risk of a static electrical charge building up and causing sparking. Preferably this should be accomplished by the use of a tank 754 composed of metalized plastic.

In Figures 8E and 8F, another pump module 770 useful in the present invention is shown. The pump module is formed to be compact, being sizable to fit into a media bay on a computer, and is formed such that when assembled all parts are secured together for ease of installation. In particular, pump module 770 includes a fluid tank housing 772, a pump 774 and a circuitry housing 776. The pump can operationally be as defined hereinabove. Fluid tank housing 772 is formed to define an inner cavity 777 and includes an open end 778 providing access to the inner cavity. An opening 779 is provided for accepting a manifold 780 including coolant fluid inlet and outlet ports. Manifold 780 is preferably mounted onto housing 772 in such a way that it can be interchanged with other manifolds depending on the size of inlets and outlets that are required to meet the flow requirements of the cooling apparatus. Housing 772 is sized to fit over and accommodate pump 774 in cavity 777 with open end 778 abutting a flange 782 on the pump.

Circuitry housing 776 includes an inner cavity 783 for accommodating circuitry (not shown), such as an inverter, and plugs 784 for connecting pump 774 to the electrical power supply of the computer in which it is installed.

Housing 776 also fits against flange 782 and end 778 to seal pump 774 therebetween. Seals are provided, as by welding, adhesives, provision of elastomeric seals, etc. such that seals are formed at least between flange 782 and end 778 to cause cavity 777 to be fluid tight and housing 776 is secured, as by welding, adhesives, clamping, etc., to the other parts to form a single pump module.

NSDOCID: <WO 03007372A2 I >

Two basic designs for the chiller module 220, 260 are shown in Figures 9 to 13. Figures 9A and 9B illustrate a copper-finned chiller 810, while Figures 10 - 13 illustrate a cylindrical aluminum-finned chiller 1010. Figures 14 - 16 illustrate a variant of the cylindrical aluminum-finned chiller 1010. Figures 17 illustrate another variant of the cylindrical aluminum-finned chiller 1010. The chillers include a chiller heat exchanger such as that shown as 814 in Figure 18, exchanger 1810 shown in Figures 19 or exchanger 1850 shown in Figures 20. The chillers operate to pass heat from the chiller to air passing thereby. As such the chillers can operate in cooperation with a fan or can be oriented to operate in a chimney fashion, without the use of a fan, wherein air moves through the chiller by convection.

As shown in Figures 9A and 9B, the copper-finned chiller 810 generally comprises a housing 812 for mounting in alignment with an opening 912 in a wall 910 of the case of the PC 210, 250, a conventional 12 volt DC fan 914, a chiller heat exchanger 814 having a chiller inlet fitting 816 and a chiller outlet fitting 818, two conventional thermoelectric heat pumps 820, 822, which are connected to the power supply of the PC 210, 250 (connection not shown), two copper base plates 824, 826, and a plurality of fins 828. An arrow 916 in Figure 9B shows the direction of airflow. When installed in the case of the PC 210, 250, the chiller inlet fitting 816 is connected to the tubing indicated by reference numerals 224, 264 and the chiller outlet fitting 818 is connected to the tubing indicated by reference numerals 226, 266.

The chiller heat exchanger 814, is essentially a block through which a chilled fluid may be circulated, is discussed in the detail below in reference to Figures 18. In the copper-finned chiller 810, the chiller heat exchanger 814 is sandwiched between the cold sides of the two thermoelectric heat pumps 820, 822 so that a large proportion of the surface area of the chiller heat exchanger 814 is thermally coupled to the cold sides of the thermoelectric heat pumps 820, 822. The assembly of the chiller heat exchanger 814 and the thermoelectric heat pumps 820, 822 is in turn sandwiched between the two copper base plates 824, 826 so that the hot sides of the thermoelectric heat pumps 820, 822 are thermally coupled to the copper base plates 824, 826, respectively. The sides of the copper base plates 824, 826 that are not

BNSDOCID: <WO 03007372A2 I >

thermally coupled to the hot sides of the thermoelectric heat pumps 820, 822 are joined by soldering or brazing to a plurality of parallel spaced apart fins 828 that are generally perpendicular to the sides of the copper base plates 824, 826.

As illustrated in Figure 9B, a buffer zone 918 is provided between the fan 914 and the finned assembly, indicated generally by reference numeral 920, that includes the chiller heat exchanger 814, the thermoelectric heat pumps 820, 822, the base plates 824, 826, and the fins 828. The purpose of the buffer zone 918 is to allow air flow from the circular outlet of the fan 914 to reach the corners of the finned assembly 920, which has a square cross-section as shown in Figure 9A.

Optionally, as shown in Figure 9A, a plurality of parallel spaced apart fins 830 may be joined to a portion of the side of a copper base plate 824 that is thermally coupled to the hot side of the thermoelectric heat pump 820, but that is not in contact with the hot side of the thermoelectric heat pump 820. Also optionally, a plurality of parallel spaced apart fins 832 may be joined to a portion of the side of the copper base plate 826 that is thermally coupled to the hot side of the thermoelectric heat pump 822, but that is not in contact with the hot side of the thermoelectric heat pump 822. If the fins 830 and 832 are omitted, then the space that they would otherwise occupy should be blocked so as to force airflow to pass between the fins 828.

In operation, the copper-finned chiller 810 chills fluid that has picked up heat from the microprocessor 214, 254 and is pumped through the chiller heat exchanger 814. The cold sides of the two thermoelectric heat pumps 820, 822 absorb heat from the chiller heat exchanger 814 and pump it to their respective hot sides. The copper base plates 824, 826 in turn transfer that heat to the fins 828, 830, 832. Air, forced between the fins 828, 830, 832 by the fan 914 picks up heat from the fins 828, 830, 832 and carries that heat out of the case of the PC 210, 250.

The cylindrical aluminum-finned chiller 1010 shown in Figures 10, 11, and 12 may be used in place of the copper-finned chiller 810. The basic difference between the two designs is in the use of four aluminum extrusions 1012, 1014, 1016, 1018 to

replace the fins 828, 830, 832 of the copper-finned chiller 810. The chiller heat exchanger 814 and the two thermoelectric heat pumps 820, 822 used in the copper-finned chiller 810 may be used in the cylindrical aluminum-finned chiller 1010 and are indicated by the same reference numerals. Two copper heat spreader plates 1020, 1022 correspond generally to the copper base plates 824, 826 of the copper-finned chiller 810.

As shown in Figures 10 - 13, the aluminum-finned chiller 1010 generally comprises a cylindrical housing 1030 that may be attached to a wall 1110 of the case of the PC 210, 250 in alignment with an opening 1112 in the wall 1110, the chiller heat exchanger 814 having a chiller inlet fitting 816 (visible only in Figure 10) and a chiller outlet fitting 818, the two thermoelectric heat pumps 820, 822, which are connected to the power supply of the PC 210, 250 (connection not shown), two copper heat spreader plates 1020, 1022, and the four aluminum extrusions 1012, 1014, 1016, 1018. An arrow 1116 in Figure 11 shows the direction of airflow. A conventional 12 volt DC fan 1114, as shown, can be used to move air through the chiller or, alternately, the chiller can be oriented such that a vertical air flow is set up through the chiller by convection. When installed in the case of the PC 210, 250, the chiller inlet fitting 816 is connected to the tubing indicated by reference numerals 224, 264 and the chiller outlet fitting 818 is connected to tubing indicated by reference numerals 226, 266.

As illustrated in Figure 11, a buffer zone 1118 is provided between the fan 1114 and the finned assembly, indicated generally by reference numeral 1120, that includes the chiller heat exchanger 814, the thermoelectric heat pumps 820, 822, the heat spreader plates 1020, 1022, and the aluminum extrusions 1012, 1014, 1016, 1018. The buffer zone 1118 shown in Figure 11 is much smaller than the buffer zone 918 shown in Figure 9 as both the fan 1114 and the finned assembly 1120 has approximately the same circular cross-sectional area so that little or no buffer zone 1118 is needed to provide airflow to the finned assembly 1120. However, the buffer zone 1118 provides space for the tubing indicated by reference numerals 224, 264 and tubing indicated by reference numerals 226, 266 to connect to the chiller heat

BNSDOCID: <WO 03007372A2 I >

exchanger 1024. Reduction in the size of the buffer zone provides a more compact chiller.

The chiller heat exchanger 814, essentially a block through which a fluid to be chilled can be circulated, is discussed in the detail below in reference to Figure 17. In the aluminum-finned chiller 1010, the chiller heat exchanger 814 is sandwiched between the two thermoelectric heat pumps 820, 822 so that a large proportion of its surface area is thermally coupled to the cold side of one or the other of the thermoelectric heat pumps 820, 822. The assembly of the chiller heat exchanger 814 and the thermoelectric heat pumps 820, 822 is in turn sandwiched between the two copper heat spreader plates 1020, 1022 so that the hot sides of the thermoelectric heat pumps 820, 822 are thermally coupled to one or the other of the copper heat spreader plates 1020, 1022. The four aluminum extrusions 1012, 1014, 1016, 1018 take the place of the fins 828, 830, 832 of the copper-finned chiller 810, and are preferred because they may be extruded as units rather than joined by soldering or brazing to the copper base plates 824, 826 as in the case of the fins 828, 830, 832 of the copper-finned chiller 810 and are formed from less expensive material (aluminum, rather than copper). The units can be adapted to enhance extrusion, such as by the provision of small parallel ridges along the surface of the material.

Aluminum extrusions 1012, 1014, 1016, 1018 are actually all identical, being merely rotated about a horizontal or vertical plane. Therefore, Figure 13, which is a cross-section through the aluminum extrusion 1012, illustrates all of them. As illustrated in Figure 13, the aluminum extrusion 1012 comprises a base 1310 from which a plurality of fins 1312 protrude.

In operation, the aluminum-finned chiller 1010 chills fluid that has picked up heat from the microprocessor 214, 254 and is pumped through the chiller heat exchanger 814. The cold sides of the two thermoelectric heat pumps 820, 822 absorb heat from the chiller heat exchanger 814 and pump it to their respective hot sides. The copper heat spreader plates 1020, 1022 in turn transfer that heat to the four aluminum extrusions 1012, 1014, 1016, 1018. Air, forced between the fins 1312 by

the fan 1114 picks up heat from the fins 1312 and carries that heat out of the case of the PC 210, 250.

Figures 14, 15, and 16 illustrate a variant, indicated generally by reference numeral 1011 of the aluminum-finned chiller 1010 of Figures 10 – 13 in which the copper heat spreader plates 1020, 1022 are omitted and the four aluminum extrusions 1012, 1014, 1016, 1018 are replaced by two identical aluminum extrusions 1015 and 1017. Figure 14 corresponds to Figure 10, Figure 15 to Figure 11, and Figure 16 to Figure 13. The elevation view of the aluminum-finned chiller 1010 provided in Figure 12 is identical for the variant 1011. Aluminum extrusion 1017 is shown in cross-section in Figure 16. As illustrated in Figure 16, the aluminum extrusion 1017 comprises a base 1610 from which a plurality of fins 1612 protrude. The base 1610 is thicker than base 1310; the extra thickness replacing the copper heat spreader plate 1020.

In operation, the variant aluminum-finned chiller 1011 chills fluid that has picked up heat from the microprocessor 214, 254 and is pumped through the chiller heat exchanger 814. The cold sides of the two thermoelectric heat pumps 820, 822 absorb heat from the chiller heat exchanger 814 and pump it to their respective hot sides. The hot sides of the two thermoelectric heat pumps 820, 822 in turn transfer that heat to the two aluminum extrusions 1015, 1017. Air, forced between the fins 1612 by the fan 1114 picks up heat from the fins 1612 and carries that heat out of the case of the PC 210, 250.

Figure 17 illustrates a variant, indicated generally by reference numeral 1011a of the aluminum-finned chiller 1010 of Figures 10 – 13 in which the four aluminum extrusions 1012, 1014, 1016, 1018 are replaced by two aluminum extrusions 1015a and 1017a and the cylindrical housing 1030 is omitted and replaced by two aluminum extrusions 1619.

Aluminum extrusions 1017a and 1015a are similar to extrusions 1015 and 1017 of Figures 14 to 16, each including a base 1610a from which a plurality of fins

BNSDOCID: <WO 03007372A2 I >

1612a', 1612a" protrude. When fully assembled, the extrusions 1015a and 1017a accommodate therebetween in space 1626 an arrangement of heat pumps and heat exchanger (not shown) in heat transfer communication with bases 1610a.

Although the extrusions are similar, fins 1612a of the present embodiment are formed differently than those illustrated in Figures 14 to 16. In particular, inwardly extending fins 1612a' are spaced apart and elongate such that the fins from the two extrusions 1015a and 1017a mesh when the extrusions are mounted together about the heat pump/heat exchanger. When meshed, fins 1612a' on opposite extrusions are spaced from each other along their side planar surfaces to permit air flow therebetween. Spacing the fins in this way provides many benefits including: facilitating extrusion of the units, assembly of the chiller module and radiant heat transfer out of the chiller. While the fins 1612a' are spaced from the base of the opposite extrusion, this is not required. In fact, the heat transfer properties of the chiller may be improved by bringing the fins into contact with the opposite extrusion.

It has been found that radiant heat transfer is further facilitated by forming the housing of conductive extrusions 1619, rather than as a non-conductive sleeve, identified as 1030 in the other aluminum chiller embodiments. Housing extrusions 1619 each include an outer wall 1621 and a plurality of fins 1620 extending therefrom. Tabs 1622 on the housing extrusions permit the extrusions 1619 to be secured together, as by use of bolts, rivets, etc. Outwardly facing fins 1612a" on extrusions 1015a and 1017a are each spaced to accommodate therebetween one of the fins 1620, such that these fins also mesh when the parts are brought together. Fins 1620 are spaced from outwardly facing fins 1612a" such that air can pass between their planar side surfaces. Fins 1620 act to absorb heat radiating from fins 1612a" and conduct it over a greater surface area, out towards wall 1621. Fins 1620 can be spaced from extrusions 1015a and 1017a about their entire surface area or alternately, they can be formed and assembled, a shown, such that the tips of fins 1620 contact against bases 1610a. Such contact permits heat to be conducted directly from the heat pump through the center extrusions and into the housing extrusions. To facilitate conduction of heat from the center extrusions into the housing extrusions, potting

material 1624, such as for example epoxy or solder, can be applied between fins 1620 and bases 1610a. Care should be taken when applying potting material 1624 to reduce, as much as possible, interference to air flow between the fins.

In addition to heat transfer, forming the chiller module according to Figure 17 also facilitates assembly thereof, wherein the parts can be built up from one half of the housing, using the meshed fins to stabilize the parts until they are secured together.

As illustrated in Figure 18, the structure of the chiller heat exchanger 814 is, in general, similar to that of the horizontal heat exchanger 258 described above in relation to Figures 5A and 5B; the primary differences being that no protrusion 356 is provided and there are 20 chambers. Chiller heat exchanger 814 comprises a central block 1410 bored through by 20 bores that are laterally connected in the manner shown in Figure 18 to form a passage from the chiller inlet fitting 816 to the chiller outlet fitting 818. An end cap 1412, 1414 covers each face of the central block 1410. A passage is provided for the circulation of a fluid that is comprised of a series of cylindrical chambers, two representative ones of which are referred to by reference numerals 1416 and 1418, connected by constrictions, a representative one of which is referred to by reference numeral 1420.

In Figure 18 fluid entering the chiller heat exchanger 814 through the chiller inlet fitting 816 passes through the 20 chambers before leaving through the chiller outlet fitting 818. Each pair of successive chambers is connected by a constriction. For example, in Figure 17 the constriction 1420 connects the pair of chambers 1416 and 1418. The chambers pass completely through the central block 1410 and may be formed by boring through a solid copper block, although casting or other methods may be used depending upon the material used. The constrictions, such as constriction 1420 also pass completely through the central block 1410, so that each of the chambers connected by the constriction has an opening in its interior wall passing into the constriction having a boundary defined by two lines along the interior wall of the chamber that run parallel to the axis of the chamber that are connected by segments of the edges of the circular ends of the chamber. The area of the opening

BNSDOCID: <WO 03007372A2 I >

should preferably by approximately equal to the cross-section area of the chiller inlet fitting 816 and the chiller outlet fitting 818.

While the chambers shown in Figure 18 are shown so that the axes of most of the successive pairs of chambers are spaced apart by slightly less than the diameter of one chamber so that most of the constrictions between successive chambers are formed by the overlapping of the chambers, it is also within the scope of the invention to space the axes of successive chambers farther apart, as shown in Figure 5B. One method for forming such chambers and constrictions is to bore a block of material so that the center of each bore is closer to the next successive bore than the diameter of the bore.

While twenty chambers are shown in Figure 18, more or fewer chambers could be used and are within the scope of this invention.

As in the case of the one-piece fluid heater exchanger 610 shown in Figures 6A – 6C, the inventor has found that the one-piece chiller heat exchanger indicated generally by reference numeral 1810 in Figures 19A – 19C is less costly to manufacture than the chiller heat exchanger 814 shown in Figure 18 and described above and may be used in place of heat exchanger 814 in many applications. However, the same design principles apply. The heat exchanger 1810 shown in Figures 6A – 6C is die cast in one piece from an aluminum alloy such as 1106 alloy or 6101 alloy using processes that are known to those skilled in the art. That process is not within the scope of the invention, although the arrangement and shapes of the internal passages are within the scope of the invention. The heat exchanger 1810 shown in Figures 19A – 19C might also be formed by molding heat conducting plastic material.

The heat exchanger 1810 shown in Figures 19A, 19B, and 19C comprises a body 1812, an inlet barb 1816, and an outlet barb 1818, all of which are die cast as a single unitary structure. Inside the body 1812 a passage 1820 shown in Figure 19C connects the opening in the inlet barb 1816 to the opening in the outlet barb 1818.

BNSDOCID: <WO 03007372A2 I >

The passage 1820 comprises a series of sixteen spherical chambers connected by fifteen cylindrical constrictions. More or fewer chambers could be used and are within the scope of this invention. Figures 19D – 19J provide a set of cross-sections showing the shapes and relative diameters of the spherical chambers and cylindrical constrictions. The transitions between the spherical chambers and constrictions are smooth.

Referring to Figures 20A and 20B, another fluid heat exchanger 1850 useful for a chiller module is shown. Fluid heat exchanger 1850 is selected to create more laminar flow therethrough than in the heat exchangers of Figures 18 and 19.

Fluid heat exchanger 1850 includes an inlet port 1852 and an outlet port 1854, each in fluid flow communication with an inner chamber 1856 defined by end walls 1858a, side walls 1858b and upper and lower walls 1858c. A plurality of ribs 1860 extend into the chamber substantially parallel with each other and substantially parallel to side walls 1858b. Ribs 1860 are spaced from end walls 1858a, as desired, to permit fluid flow between the ribs and through the chamber. As such ribs 1860, walls 1858a and 1858b form a plurality of fluid flow pathways therebetween between inlet port 1852 and outlet port 1854.

Ribs 1860 are formed in heat conductive communication with walls 1858c such that heat from the fluid flowing therepast can be conducted through the ribs and into the walls of the heat exchanger.

Heat exchanger 1850 is easy to manufacture from two identical extrusions 1862 formed of heat conductive material, such as aluminum, having a walls 1858b, 1858c and ribs 1860. The extrusions can be modified by removing end sections of the ribs at their ends, meshed together and joined, as by welding, adhesives, etc. to be liquid tight. End walls 1858a having port openings therein can then be mounted, in a liquid tight manner onto the ends.

BNSDOCID: <WO 03007372A2 I >

Fluid can flow through the heat exchanger in a number of ways. Figures 20B and 20C show two such ways. In particular, in one embodiment, the inlet and outlet ports 1852, 1854 can be formed as in Figure 20A at one end and fluid can flow, as shown by arrows 20B from one end to the other of the chiller heat exchanger through the pathways formed by ribs 1860a and return through the pathways formed by ribs 1860b back toward the ported end. In another embodiment, the inlet port 1852a is formed on a wall opposite the outlet port 1854a and flow occurs, as indicated by arrows 20c. Flow is generated through all ribs by offsetting the inlet and the outlet ports.

A molded retainer can be used, as shown in Figures 21A, 21B, and 21C for coupling the fluid heat exchanger 218, 258, 612 to a microprocessor. The molded retainer, generally indicated by reference numeral 1910, may be used instead of the plastic bar 322 and spring clips 324 in Figure 3A and the plastic bar 362 and spring clips 364 shown in Figure 3B. The molded retainer 1910 comprises a plate 1912 of plastic material having a front hook 1914 and a rear hook 1916 that extend perpendicularly from the plate 1912 and perform the same function as the spring clips 324, 364. Portions of the hooks 1914, 1916 near the ends that do not hook to the socket 216, 256 are embedded in the plate 1912 rather than fastened to the edges of the plate 1912 by screws as is the case in the plastic bar 322, 362 and spring clips 324, 364 shown in Figures 3A and 3B. Further, the ends of the hooks 1914 and 1916 that do not hook to the socket 216, 256 are bent back after they emerge from the plate 1912 and extend perpendicularly from the plate 1912 to form side brackets 1918. The side brackets 1918 extend far enough to restrain the body of the fluid heat exchanger from twisting. Two further side brackets 1920 each having a end molded into the plate 1912 are provided so that the body of the fluid heat exchanger is surrounded on all four sides by brackets 1918, 1920. The hooks 1914, 1918 and brackets 1918, 1920 are preferably made from 26 gauge sheet steel. As in the case of the plastic bar 322, 362, the plate 1912 is provided with an opening 1922 that is threaded to accept a bolt (not shown) that may be the same as the bolt shown in Figures 3A and 3B. The opening 1922 is located so that the bolt is aligned with the center of the die 210, 250 when the retainer is installed in place of the plastic bar 322, 362 shown in Figures 3A

NSDOCID: <WO 03007372A2 I >

and 3B. The plastic used to form the plate 1912 may be acrylic, although other plastics or other material may be used. The material used and its thickness should be selected so that the plate 1912 will break if the bolt is over-tightened.

Those skilled in the art will understand that the invention may be used to cool electronic components such as graphics processors as well as microprocessors by adding additional fluid heat exchanger modules either in series or in parallel with the fluid heat exchanger used to cool the microprocessor. Similarly, multiprocessor computers can be cooled using multiple fluid heat exchangers.

Other embodiments will be apparent to those skilled in the art and, therefore, the invention is defined in the claims.

BNSDOCID: <WO 03007372A2 I >

What is claimed is:

1. A heat exchanger for extracting heat from a microprocessor whose die has an exposed non-active surface extending above and parallel to a generally planar surface of said microprocessor, comprising:

a body through which a fluid may be circulated;

a protrusion extending from said body, said protrusion having

a first surface that is substantially congruent with and conforms to said non-active surface and may be thermally coupled to said non-active surface and

a sidewall that extends between the boundary of said first surface and said body; and

a heat-conducting path extending from said first surface through said protrusion to a region of said body that is thermally coupled to said fluid when said fluid is circulated through said body.

2. The heat exchanger as defined in claim 1, wherein a passage is provided within said body through which said fluid may be circulated, said passage comprising a series of generally spherical chambers separated by generally cylindrical constrictions, and the transitions between the chambers and the constrictions are smooth.

3. The heat exchanger as defined in claim 2, wherein said sidewall is generally perpendicular to the said first surface at its line of contact therewith and has a radius of curvature of at least six mm and the surface of said body is at least six mm from the plane of said first surface.

4. The heat exchanger as defined in claim 1, wherein:

said body is cuboid, having broad parallel upper and lower faces and four sides;

said protrusion extends downward from said lower face; and

said sidewall has a radius of curvature that is approximately equal to the perpendicular distance between the plane of said first surface and said lower face.

5. The heat exchanger as defined in claim 4, wherein a passage is provided within said body through which said fluid may be circulated, said passage comprising a series of chambers separated by constrictions.

6. The heat exchanger as defined in claim 5, wherein the chambers are generally spherical, the constrictions are generally cylindrical, and the transitions between the chambers and the constrictions are smooth.

7. The heat exchanger as defined in claim 6, wherein the perpendicular distance between the plane of said first surface and said lower face is at least six mm.

8. The heat exchanger as defined in claim 7, wherein the heat exchanger is cast in one piece from an aluminum alloy.

9. A heat exchanger for extracting heat from an electronic device through a hot portion of the surface of said electronic device, comprising:

a body through which a fluid may be circulated;

a protrusion extending from said body, said protrusion having a first surface that may be thermally coupled to said hot portion and a sidewall that extends between the boundary of said first surface and said body; and

BNSDOCID: <WO 03007372A2 I >

a heat-conducting path extending from said first surface through said protrusion to a region of said body that is thermally coupled to said fluid when said fluid is circulated through said body,

wherein when said first surface is thermally coupled to said hot portion, the surface of said body is sufficiently distant from said surface of said electronic device that ambient air may circulate therebetween..

10. The heat exchanger as defined in claim 9, wherein said electronic device is a microprocessor comprising a die mounted in a package and the said hot portion is thermally coupled to said die.

11. The heat exchanger as defined in claim 10, wherein:

said electronic device is a microprocessor comprising a die mounted in a package;

said package has a generally planar upper surface above which a planar non-active surface of said die extends; and

said non-active surface is said hot portion.

12. The heat exchanger as defined in claim 11, wherein said first surface is substantially congruent with and conforms to said non-active surface.

13. The heat exchanger as defined in claim 12, wherein a passage is provided within said body through which said fluid may be circulated, said passage comprising a series of chambers separated by constrictions.

14. The heat exchanger as defined in claim 13, wherein said passage follows a path through said body that is topologically equivalent to a spiral, entering said body at a location adjacent to said protrusion and winding in a direction generally away from said protrusion.

15. The heat exchanger as defined in claim 14, wherein said heat exchanger is comprised of:

a central section having a first face and a second face that are substantially parallel to each other;

a first side section and a second side section, each said side section having two substantially parallel faces, one face of the first side section mating with said first face of said central section and one face of said second side section mating with said second face of said central section; and

two end caps for mating with said faces of said side sections not mating with said central section,

wherein:

said protrusion extends from said central section,

each said section contains interior spaces each of which opens to both faces of said section, said side sections having selected ones of said interior spaces connected together within said side sections so that said passage is formed when said sections and said end caps are mated together, and

said heat exchanger is assembled by joining said mating faces together.

16. The heat exchanger as defined in claim 15, wherein said internal spaces are defined by substantially cylindrical walls that are substantially perpendicular to the faces of said sections.

BNSDOCID: <WO 03007372A2 I >

17. The heat exchanger as defined in claim 13, further comprising a heat pipe extending from within said protrusion into said body, whereby said heat pipe provides a portion of said heat-conducting path.

18. The heat exchanger as defined in claim 17, wherein said protrusion includes a heat-conducting plate, one of the surfaces of said plate thermally coupled to said heat pipe and the other surface of said plate providing said first surface.

19. The heat exchanger as defined in claim 18, said heat pipe comprising a cavity defined by said heat-conducting plate, a cylindrical bore beginning at said heat-conducting plate, passing through said protrusion and said body, and ending in an opening at the end of said bore opposite to said heat-conducting plate, said opening for receiving a plug to seal said cavity.

20. The heat exchanger as defined in claim 19, wherein said passage follows a path through said body that is topologically equivalent to a spiral, entering said body at a location adjacent to said protrusion and winding around said heat pipe and away from said protrusion.

21. The heat exchanger as defined in 20, wherein said heat exchanger is comprised of:

a central section having a first face and a second face that are substantially parallel to each other;

a first side section and a second side section, each said side section having two substantially parallel faces, one face of the first side section mating with said first face of said central section and one face of said second side section mating with said second face of said central section; and

two end caps for mating with said faces of said side sections not mating with said central section,

INSDOCID: <WO 03007372A2 I >

wherein:

said protrusion extends from said central section,

each said section contains interior spaces each of which opens to both faces of said section, said side sections having selected ones of said interior spaces connected together within said side sections so that said passage is formed when said sections and said end caps are mated together, and

said heat exchanger is assembled by joining said mating faces together.

22. The heat exchanger as defined in claim 21, wherein said internal spaces are defined by substantially cylindrical walls that are substantially perpendicular to the faces of said sections.

23. The heat exchanger as defined in claim 22, wherein said heat pipe is in said central section.

24. A heat exchanger for extracting heat from an electronic device through a hot portion of the surface of said electronic device, comprising a body through which a fluid may be circulated, said body having:

a first surface that may be thermally coupled to said hot portion; and

a heat-conducting path from said first surface to a region of said body that is thermally coupled to said fluid when said fluid is circulated through said body,

such that, when said first surface is thermally coupled to said hot portion, the surface of said body other than said first surface is sufficiently distant from the surface of said electronic device other than said hot portion that ambient air may circulate therebetween.

BNSDOCID: <WO 03007372A2 I >

25. The heat exchanger as defined in claim 24, wherein said electronic device is a microprocessor comprising a die mounted in a package, said package having a generally planar upper surface above which a planar non-active surface of said die extends, and said non-active surface is said hot portion.

26. The heat exchanger as defined in claim 25, wherein said first surface is substantially congruent with and conforms to said hot portion so that said first surface may be thermally coupled to said hot portion.

27. A heat exchanger for extracting heat from an electronic device through a hot portion of the surface of said electronic device, comprising:

a body that may be cooled by a circulating fluid, said body having a first surface that may be thermally coupled to said hot portion;

a conduit for circulating said fluid; and

a heat-conducting path from said first surface to a portion of said body that is thermally coupled to said fluid when said fluid is circulated,

such that when said first surface is thermally coupled to said hot portion the surface of said body other than said first surface and the conduit are sufficiently distant from the surface of said electronic device other than said hot portion that ambient air may circulate therebetween.

28. The heat exchanger as defined in claim 27, wherein said conduit for circulating said fluid is substantially outside said body.

29. The heat exchanger as defined in claim 28, wherein said conduit for circulating said fluid comprises a length of tubing wound around said body.

30. The heat exchanger as defined in claim 29, wherein said body has a protrusion and said first surface is located on said protrusion.

31. The heat exchanger as defined in claim 30, wherein said electronic device is a microprocessor comprising a die mounted in a package, said package having a generally planar upper surface above which a parallel planar non-active surface of said die extends, and the said hot portion is said non-active surface of said die.

32. The heat exchanger as defined in claim 31, wherein said first surface is substantially congruent with and conforms to said hot portion so that said first surface may be thermally coupled to said hot portion.

33. An apparatus for cooling an electronic device, comprising:

a first fluid heat exchanger for transferring heat from a hot portion of the surface of said electronic device to a fluid, said first fluid heat exchanger comprising

a body through which said fluid may be circulated,

a protrusion extending from said body, said protrusion having a first surface that may be thermally coupled to said hot portion and a sidewall that extends between the boundary of said first surface and said body, and

a heat-conducting path extending from said first surface through said protrusion to a region of said body that is thermally coupled to said fluid when said fluid is circulated through said body;

a chiller for chilling said fluid; and

a pump for circulating said fluid through said chiller and said first fluid heat exchanger.

BNSDOCID: <WO 03007372A2 I >

34. The apparatus as defined in claim 33, wherein said electronic device is a microprocessor comprising a die mounted in a package, said package having a generally planar upper surface above which a planar non-active surface of said die extends, and the said hot portion is said non-active surface.

35. The apparatus as defined in claim 34, wherein said first surface is substantially congruent with and conforms to said hot portion so that said first surface may be thermally coupled to said hot portion.

36. The apparatus as defined in claim 35, wherein when said first surface is thermally coupled to said hot portion, the surface of said body is sufficiently distant from said upper surface that ambient air may circulate therebetween.

37. The apparatus as defined in claim 35, wherein said sidewall is generally perpendicular to the said first surface and all of the surface of said body is at least six mm from the plane of said first surface.

38. The apparatus as defined in claim 35, wherein a passage is provided within said body through which said fluid may be circulated, said passage comprising a series of chambers separated by constrictions.

39. The apparatus as defined in claim 38, wherein said passage follows a path through said body that is topologically equivalent to a spiral, entering said body at a location adjacent to said protrusion and winding in a direction generally away from said protrusion.

40. The apparatus as defined in claim 39, wherein said first heat exchanger is comprised of:

a central section having a first face and a second face that are substantially parallel to each other;

NSDOCID: <WO 03007372A2 I >

a first side section and a second side section, each said side section having two substantially parallel faces, one face of the first side section mating with said first face of said central section and one face of said second side section mating with said second face of said central section; and

two end caps for mating with said faces of said side sections not mating with said central section,

wherein:

said protrusion extends from said central section,

each said section contains interior spaces each of which opens to both faces of said section, said side sections having selected ones of said interior spaces connected together within said side sections so that said passage is formed when said sections and said end caps are mated together, and

said first heat exchanger is assembled by joining said mating faces together.

41. The apparatus as defined in claim 38, further comprising a heat pipe extending from within said protrusion into said body, whereby said heat pipe provides a portion of said heat-conducting path.

42. The apparatus as defined in claim 41, wherein said protrusion includes a heat-conducting plate, one of the surfaces of said plate thermally coupled to said heat pipe and the other surface of said plate providing said first surface.

43. The apparatus as defined in claim 42, said heat pipe comprising a cavity defined by said heat-conducting plate, a cylindrical bore beginning at said heat-conducting plate, passing through said protrusion and said body, and ending in an opening at the end of said bore opposite to said heat-conducting plate, said opening for receiving a plug to seal said cavity.

BNSDOCID: <WO 03007372A2 I >

44. The apparatus as defined in claim 43, wherein said passage follows a path through said body that is topologically equivalent to a spiral, entering said body at a location adjacent to said protrusion and winding around said heat pipe and away from said protrusion.

45. The apparatus as defined in claim 44, wherein said first heat exchanger is comprised of:

a central section having a first face and a second face that are substantially parallel to each other;

a first side section and a second side section, each said side section having two substantially parallel faces, one face of the first side section mating with said first face of said central section and one face of said second side section mating with said second face of said central section; and

two end caps for mating with said faces of said side sections not mating with said central section,

wherein:

said protrusion extends from said central section,

each said section contains interior spaces each of which opens to both faces of said section, said side sections having selected ones of said interior spaces connected together within said side sections so that said passage is formed when said sections and said end caps are mated together, and

said first heat exchanger is assembled by joining said mating faces together.

46. The heat exchanger as defined in claim 45, wherein said internal spaces are defined by substantially cylindrical walls that are substantially perpendicular to the faces of said sections.

47. The heat exchanger as defined in claim 46, wherein said heat pipe is in said central section.

48. The heat exchanger as defined in claim 47, wherein said heat pipe contains a mixture consisting essentially of acetone, isopropyl alcohol, and water as a working fluid.

49. The apparatus as defined in claim 33, wherein said chiller comprises:

a second fluid heat exchanger through which said fluid may be circulated;

a heat spreader plate one face of which is thermally coupled to said second heat exchanger; and

a stack of spaced-apart heat conductive fins, each of which is thermally coupled to said heat spreader plate and extending from the face of said heat spreader plate opposite to said face of said heat spreader plate that is thermally coupled to said second fluid heat exchanger.

50. The apparatus as defined in claim 49, further comprising a fan oriented to blow air between said fins.

51. The apparatus as defined in claim 50, further comprising a thermoelectric cooler having a cool face and a warm face when connected to a power source, said thermoelectric cooler interposed between said second fluid heat exchanger and said heat spreader plate so that said cool face is thermally coupled to said second fluid heat exchanger and said warm face is thermally coupled to said heat spreader plate.

BNSDOCID: <WO 03007372A2 I >

52. The apparatus as defined in claim 33, wherein said chiller comprises:

a second fluid heat exchanger through which said fluid may be circulated, said second fluid heat exchanger having two substantially parallel extended faces;

two heat spreader plates, each having a first extended face thermally coupled to a discrete extended face of said second fluid heat exchanger and each having a second extended face substantially parallel to its first extended face; and

two stacks of spaced-apart heat conductive fins, each stack thermally coupled to said second extended face of a discrete one of said heat spreader plates so that said fins are substantially perpendicular to a plane that is parallel to said heat spreader plates.

53. The apparatus as defined in claim 52, wherein all of said fins are substantially parallel to a each other.

54. The apparatus as defined in claim 53, further comprising a fan oriented to blow air between all of said fins in a direction substantially parallel to said heat spreader plates.

55. The apparatus as defined in claim 54, further comprising a cylindrical housing, wherein said fan, said second fluid heat exchanger, said heat spreader plates, and said fin stacks are mounted inside said housing.

56. The apparatus as defined in claim 55, wherein the lengths of said fins are selected so that each extends to the interior wall of said housing.

57. The apparatus as defined in claim 56, wherein each fin stack includes a base plate and is extruded as a unitary structure.

58. The apparatus as defined in claim 56, wherein each heat spreader plate and associated fin stack is extruded as a unitary structure.

59. The apparatus as defined in claim 52, further comprising two thermoelectric coolers, each having a cool face and a warm face when connected to a power source, each thermoelectric cooler interposed between said second fluid heat exchanger and a discrete one of said heat spreader plates so that said cool face of each said thermoelectric cooler is thermally coupled to said second fluid heat exchanger and said warm face is thermally coupled to one of said heat spreader plates.

60. The apparatus as defined in claim 33, further comprising a tank and wherein said pump is a submersible-type pump and is housed in said tank so that when in operation said pump is submerged in said fluid.

61. The apparatus as defined in claim 60, wherein said pump requires AC power and further comprising a DC to AC inverter for providing AC power to said pump.

BNSDOCID: <WO 03007372A2 I >

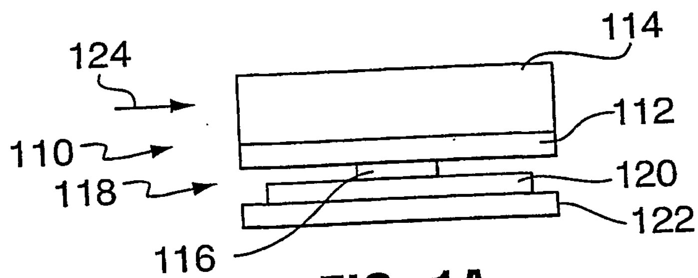


FIG. 1A
PRIOR ART

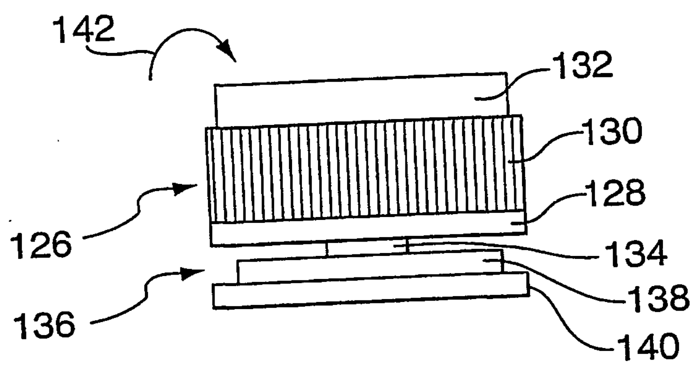


FIG. 1B
PRIOR ART

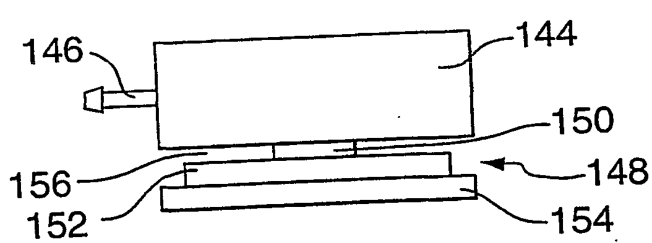


FIG. 1C
PRIOR ART

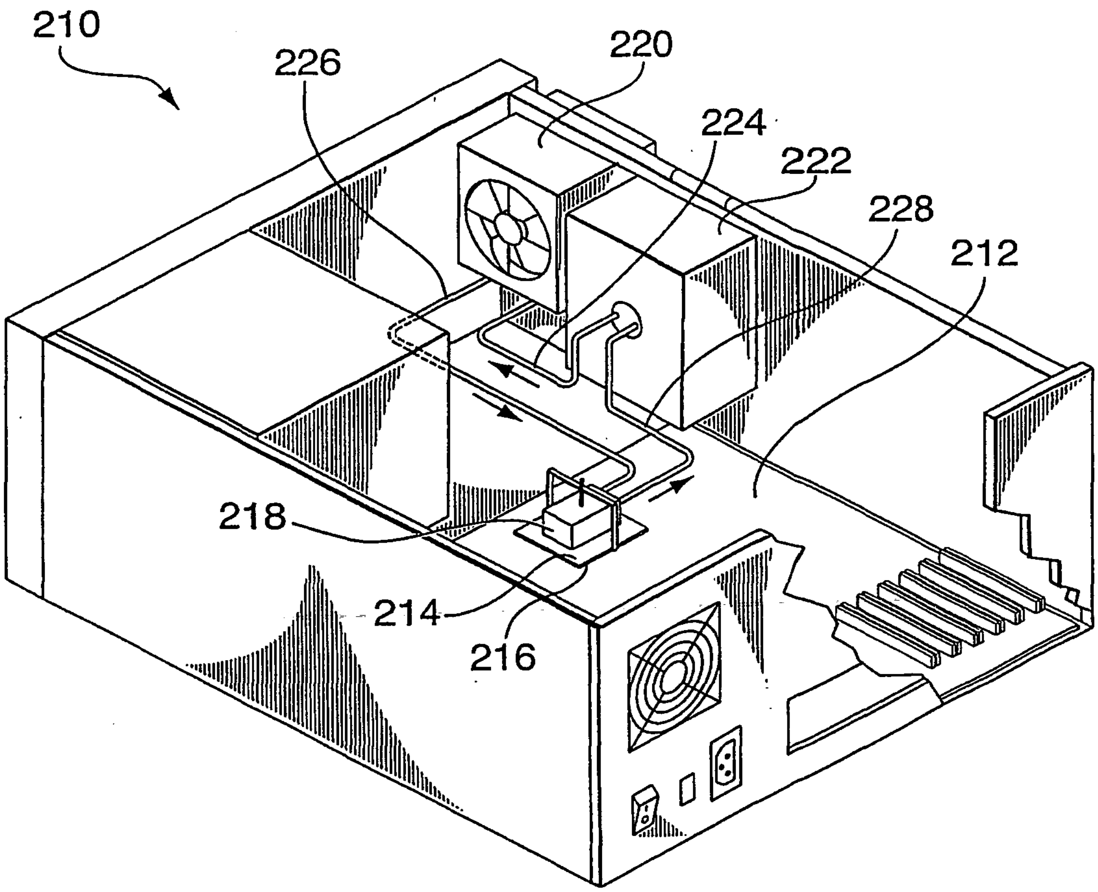


FIG. 2A

BNSDOCID: <WO 03007372A2 I >

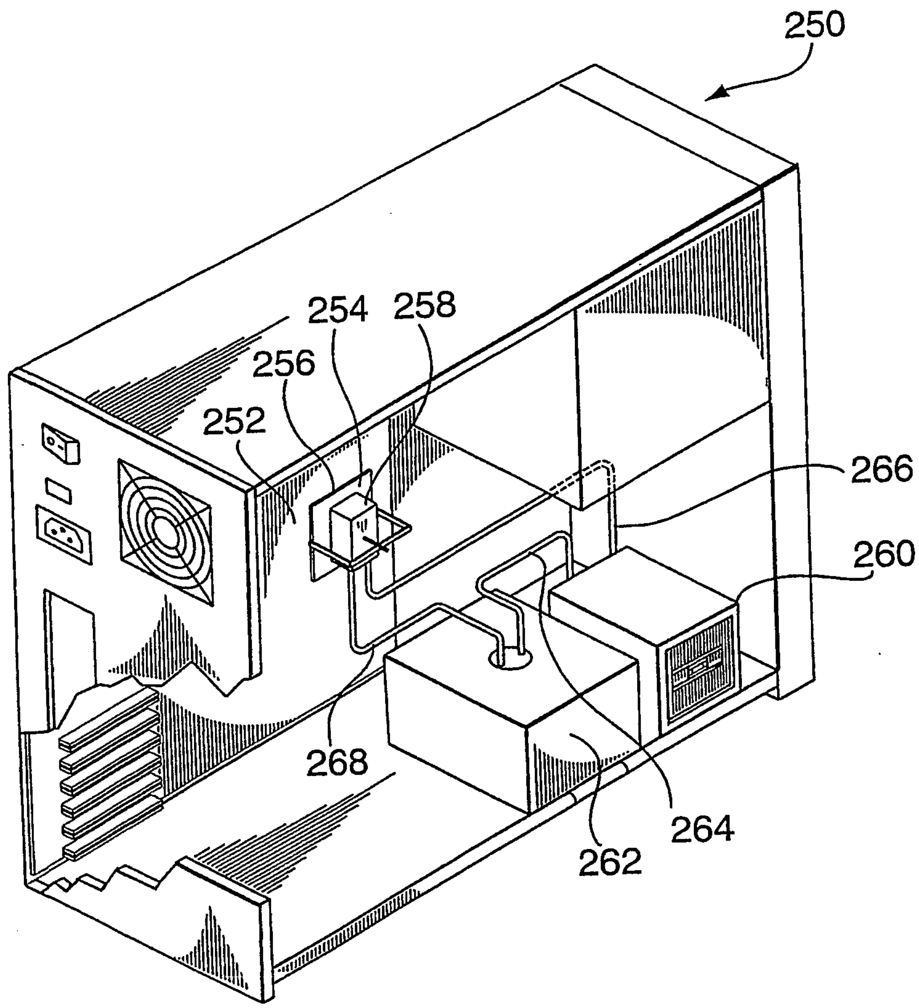


FIG. 2B

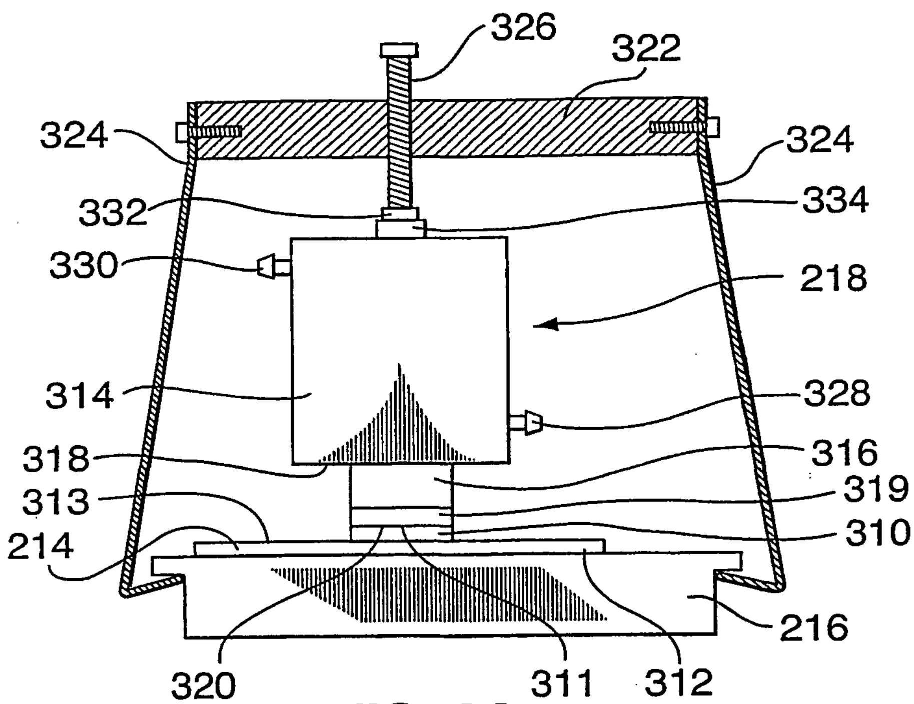


FIG. 3A

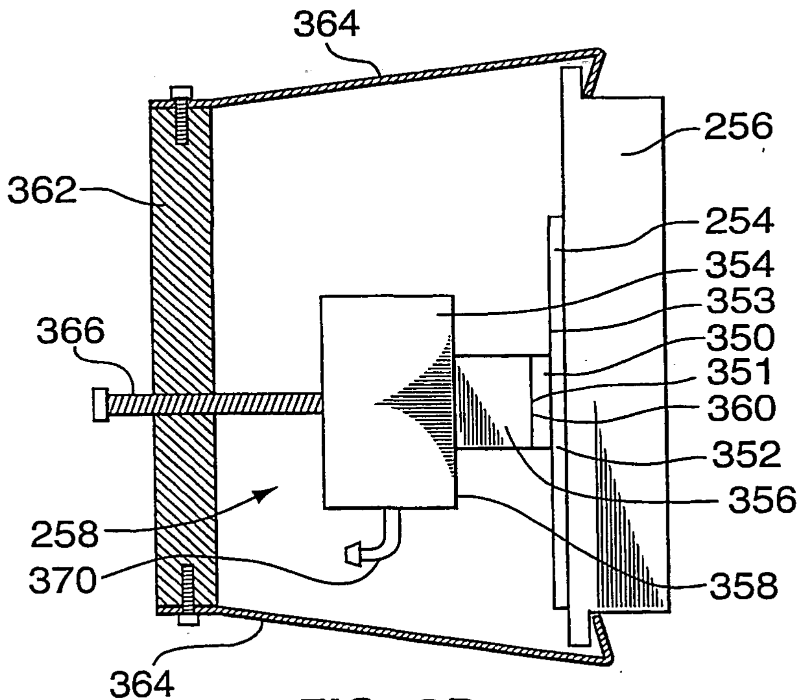


FIG. 3B

BNSDOCID: <WO 03007372A2 I >

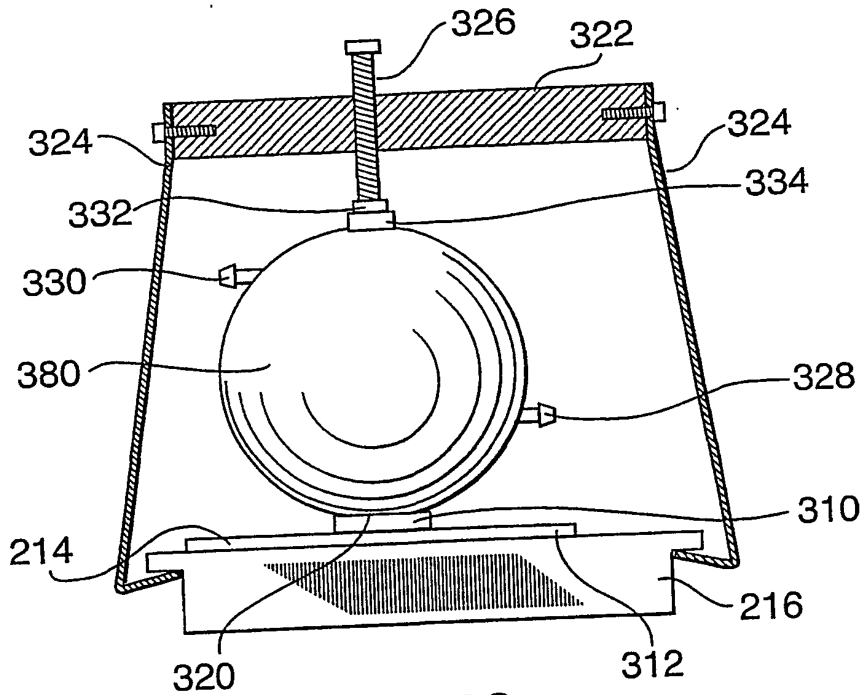

326
322
324
324
334
332
330
380
328
310
214
216
320
312

FIG. 3C

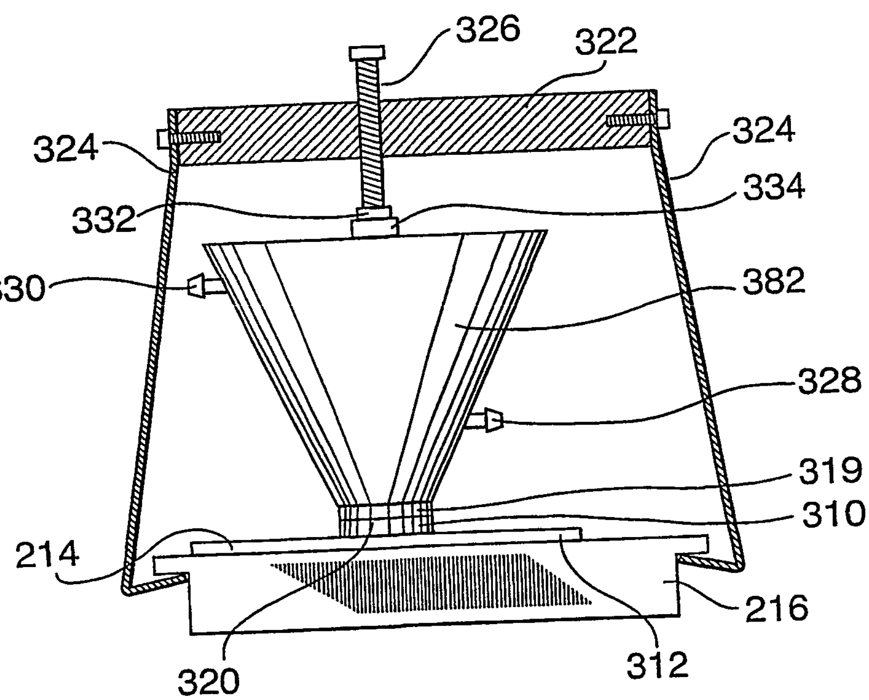

326
322
324
324
334
332
382
330
328
319
310
214
216
320
312

FIG. 3D

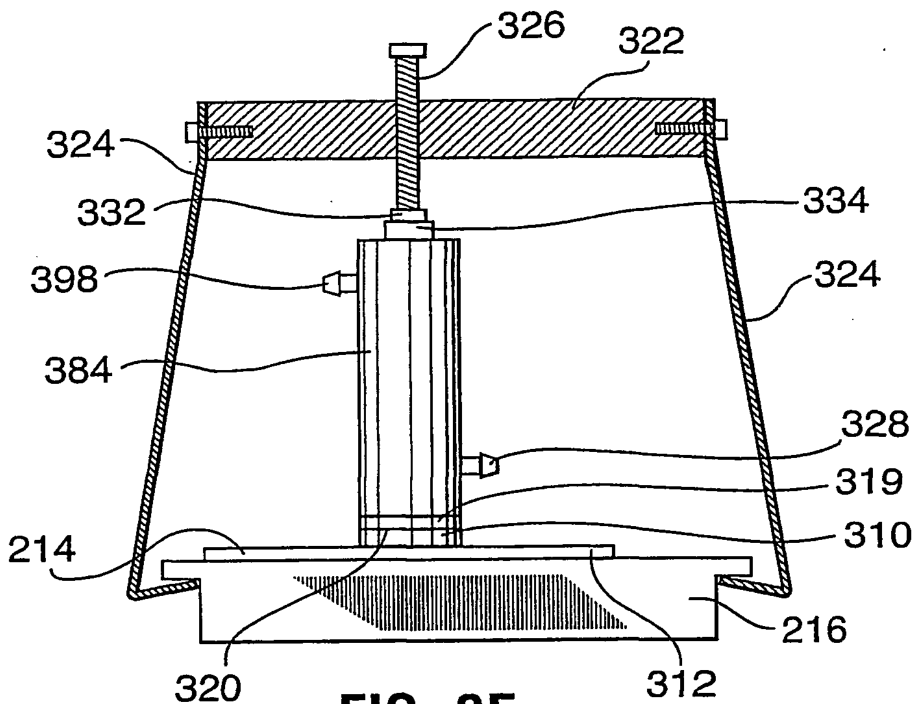

326
322
324
332
334
398
324
384
328
319
310
214
216
320
312

FIG. 3E

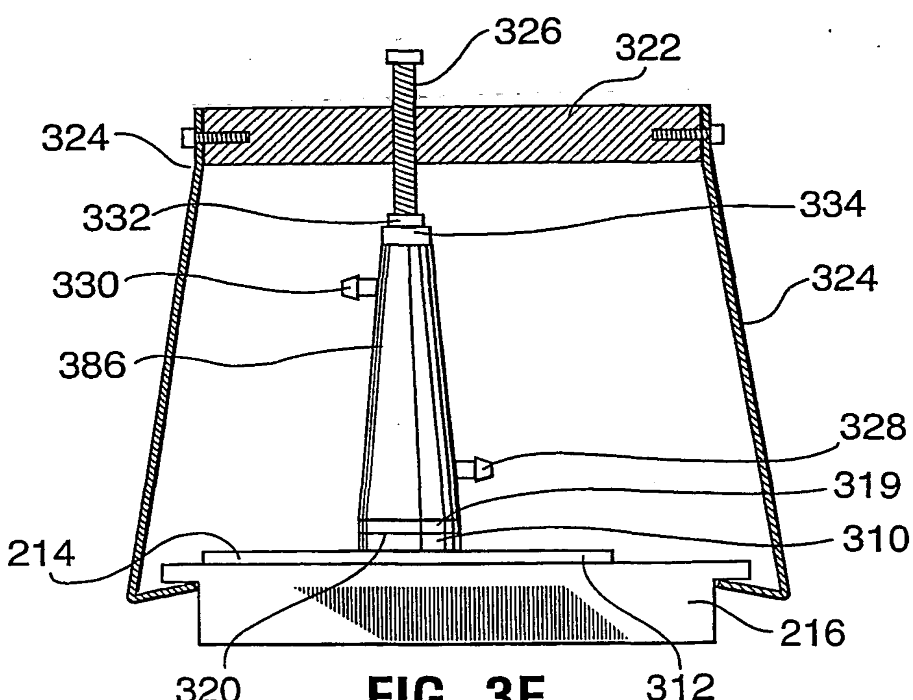

326
322
324
332
334
330
324
386
328
319
310
214
216
320
312

FIG. 3F

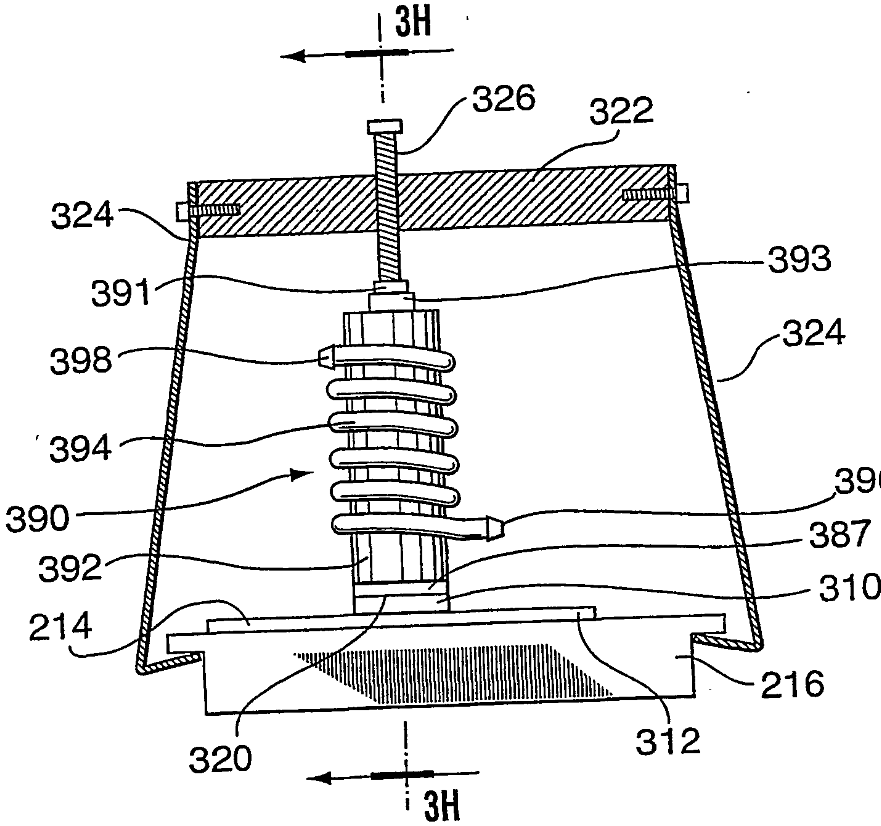

3H
326
322
324
391
393
398
324
394
396
390
387
392
310
214
216
320
312
3H

FIG. 3G

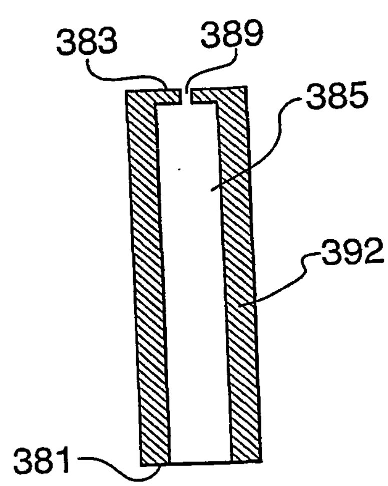

383
389
385
392
381

FIG. 3H

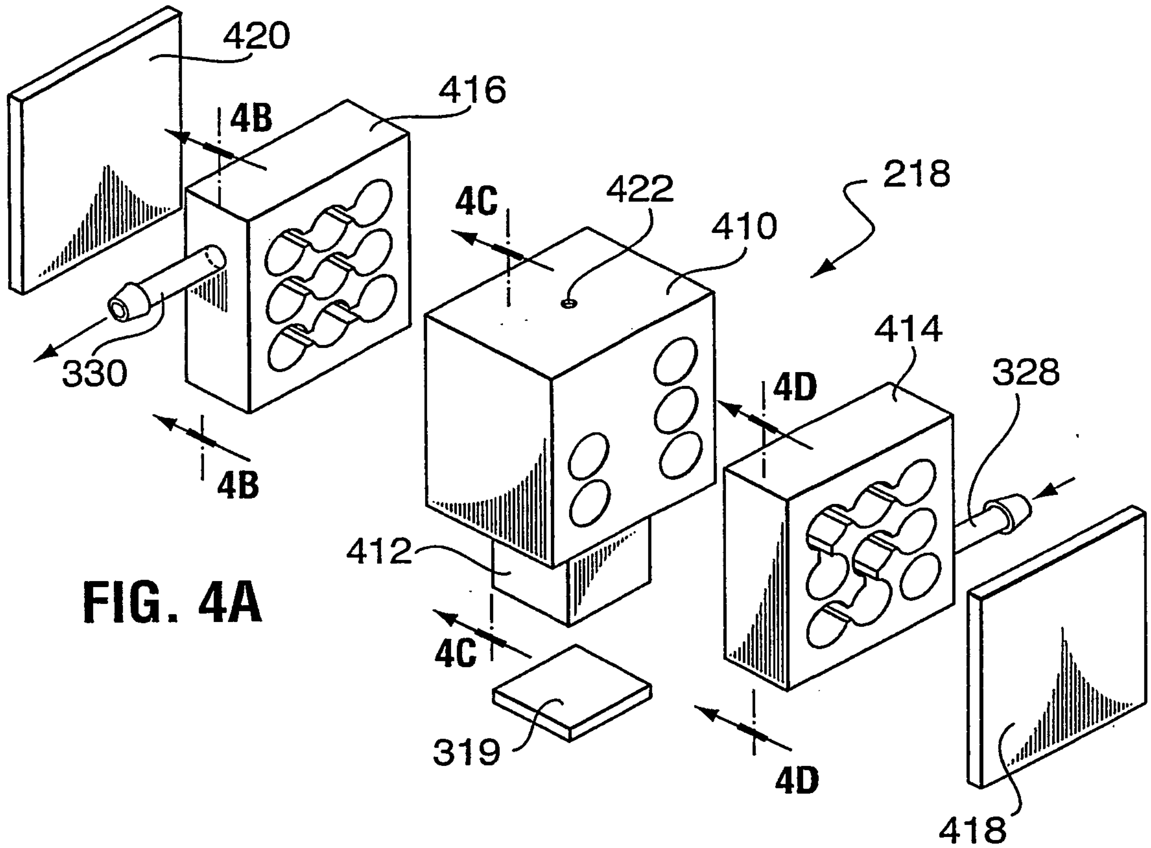


FIG. 4A

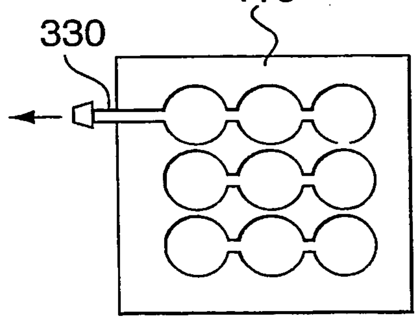


FIG. 4B

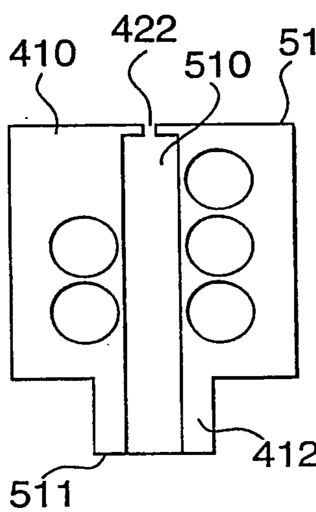


FIG. 4C

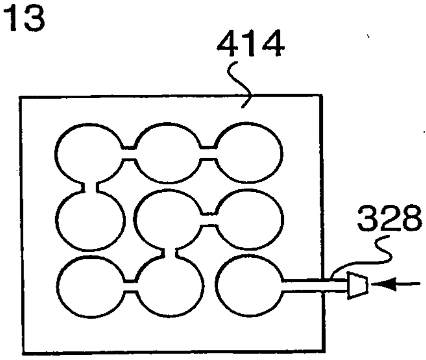


FIG. 4D

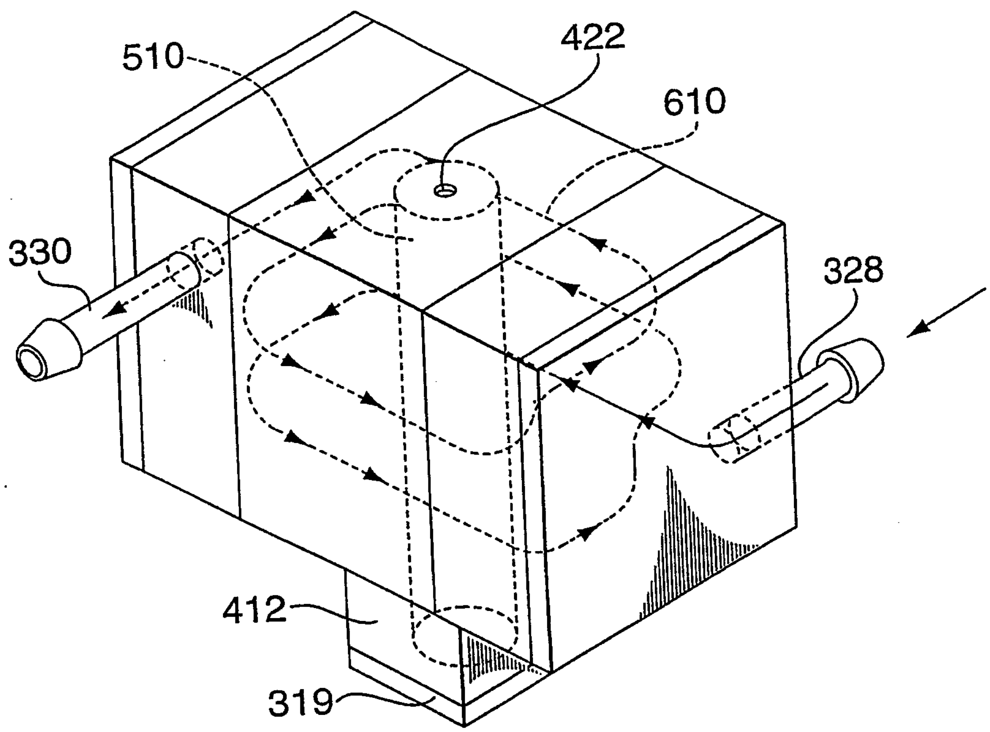


FIG. 4E

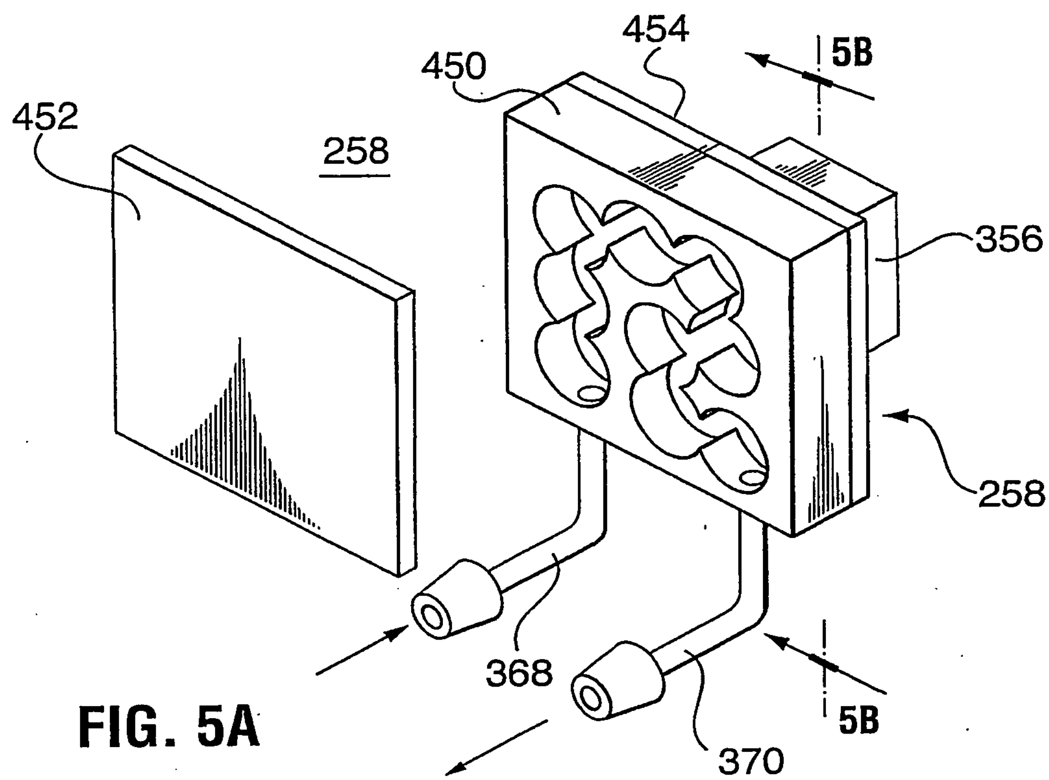


FIG. 5A

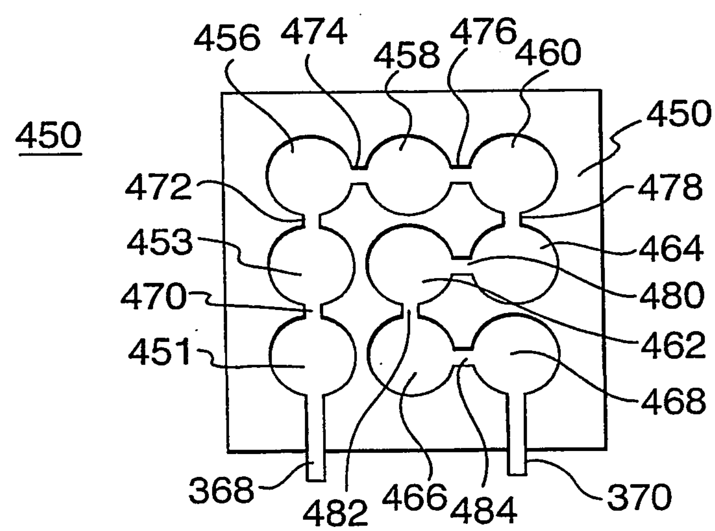


FIG. 5B

BNSDOCID: <WO 03007372A2 I >

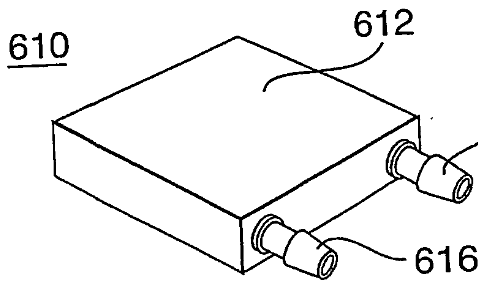


FIG. 6A

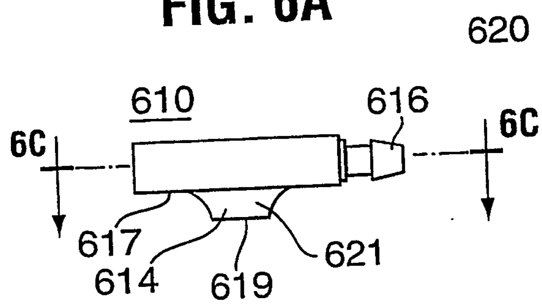


FIG. 6B

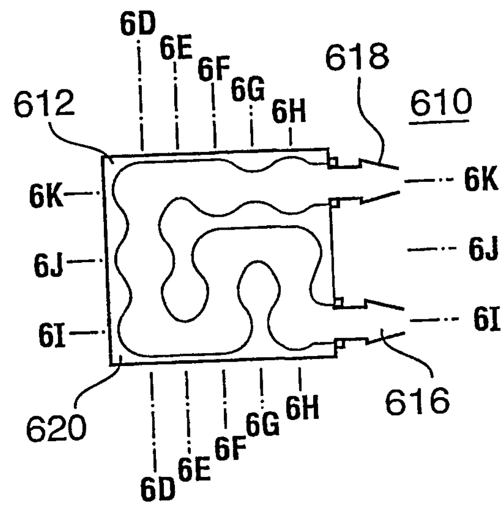


FIG. 6C

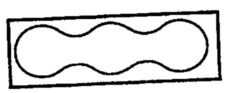


FIG. 6D

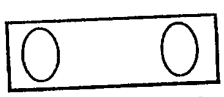


FIG. 6E

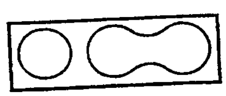


FIG. 6F

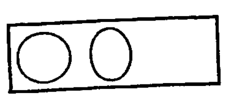


FIG. 6G

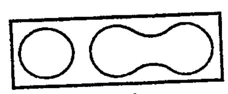


FIG. 6H

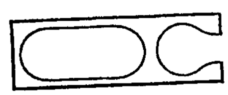


FIG. 6I

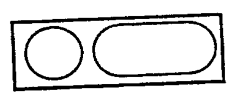


FIG. 6J

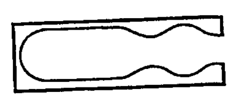


FIG. 6K

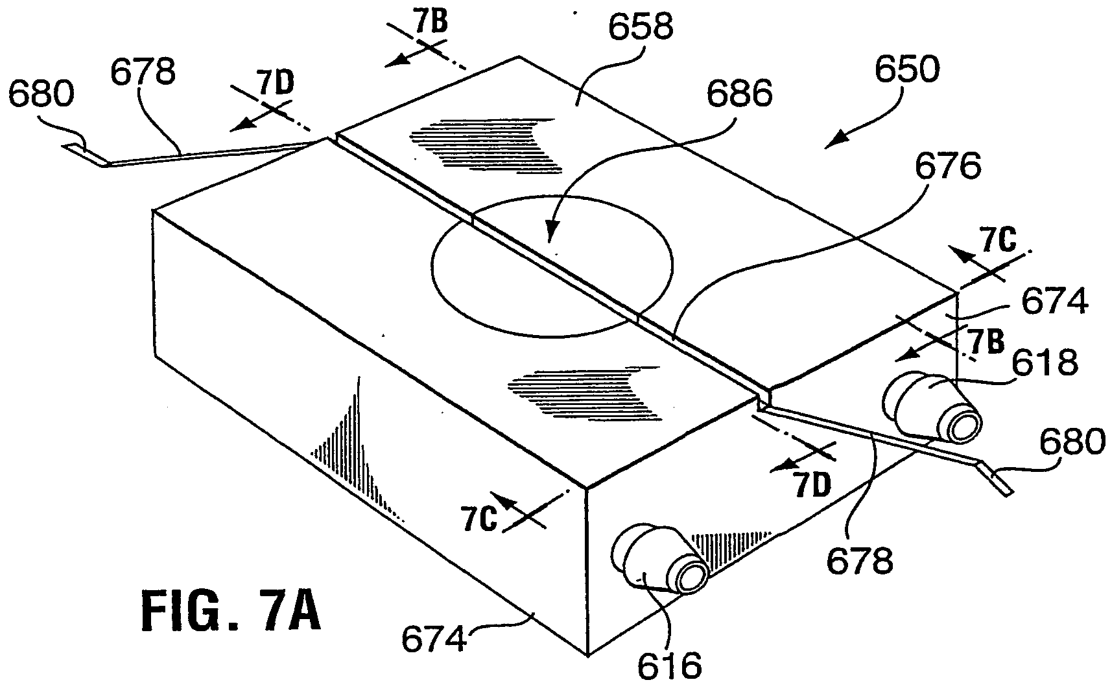


FIG. 7A

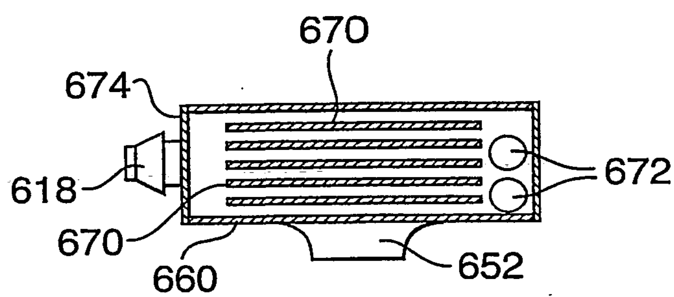


FIG. 7B

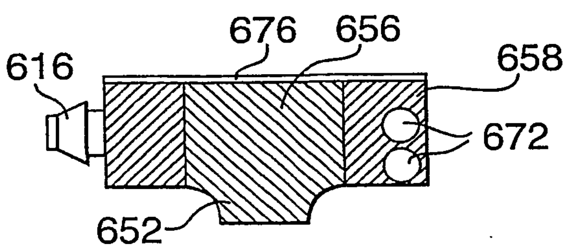


FIG. 7D

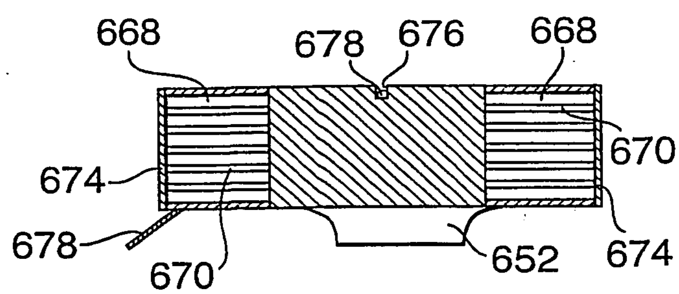


FIG. 7C

BNSDOCID: <WO 03007372A2 I >

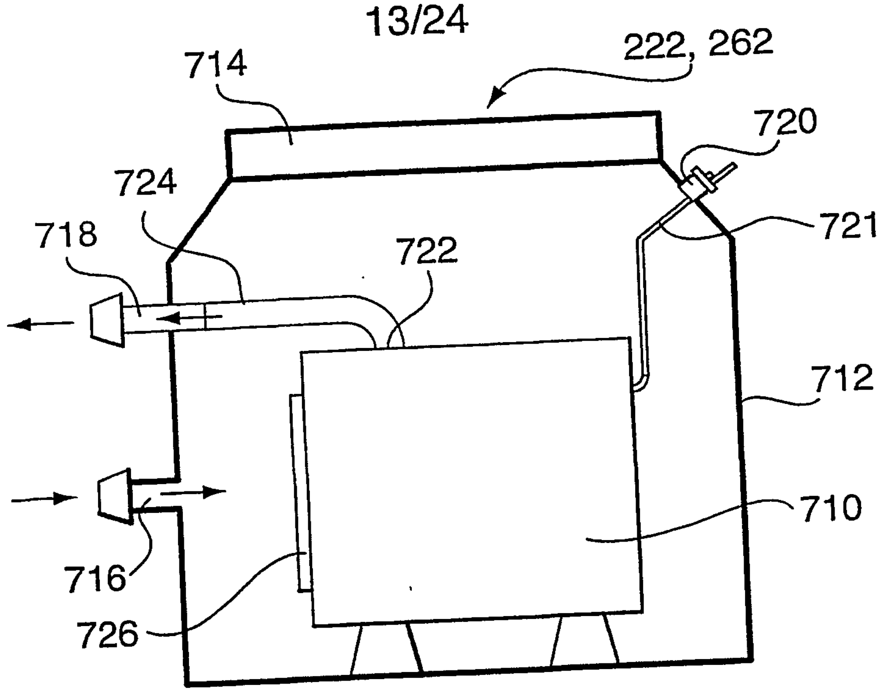


FIG. 8A

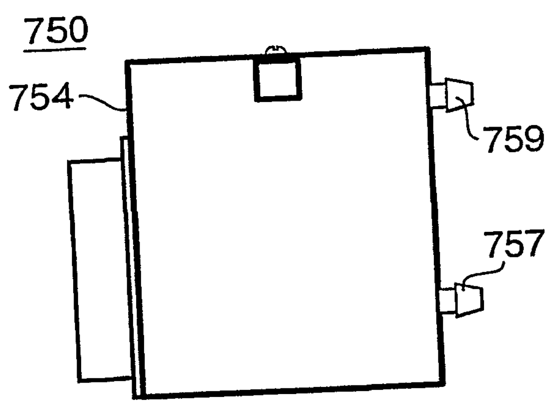


FIG. 8B

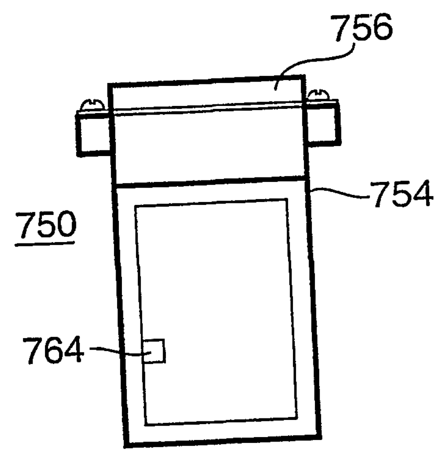


FIG. 8C

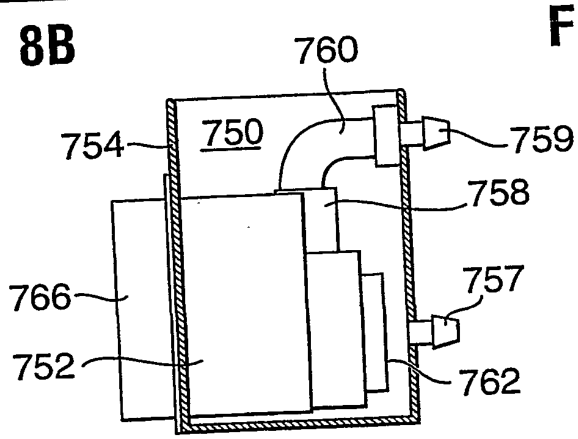


FIG. 8D

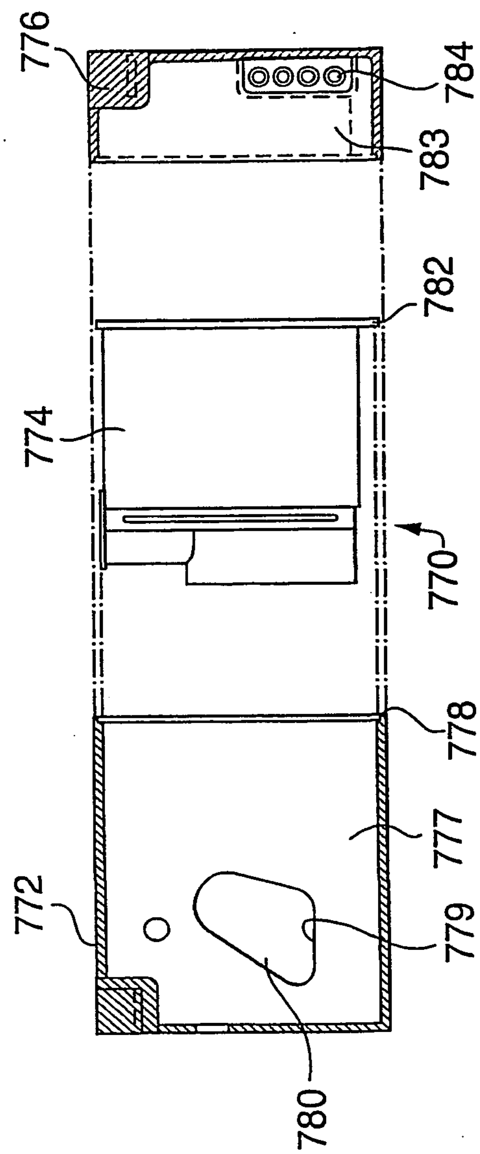

776
784
783
782
774
770
778
777
772
779
780

FIG. 8E

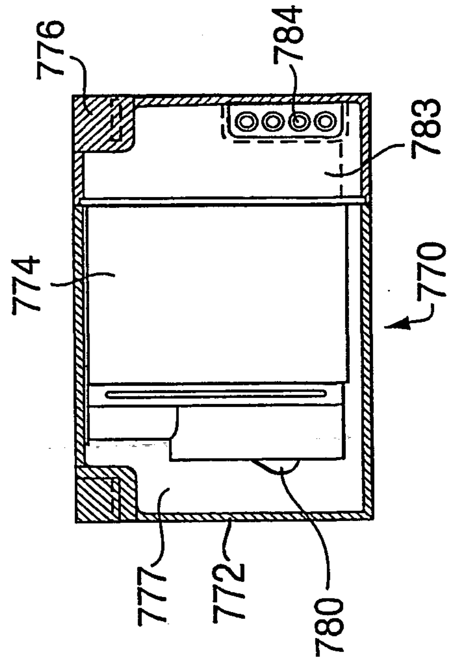

776
784
783
774
770
777
772
780

FIG. 8F

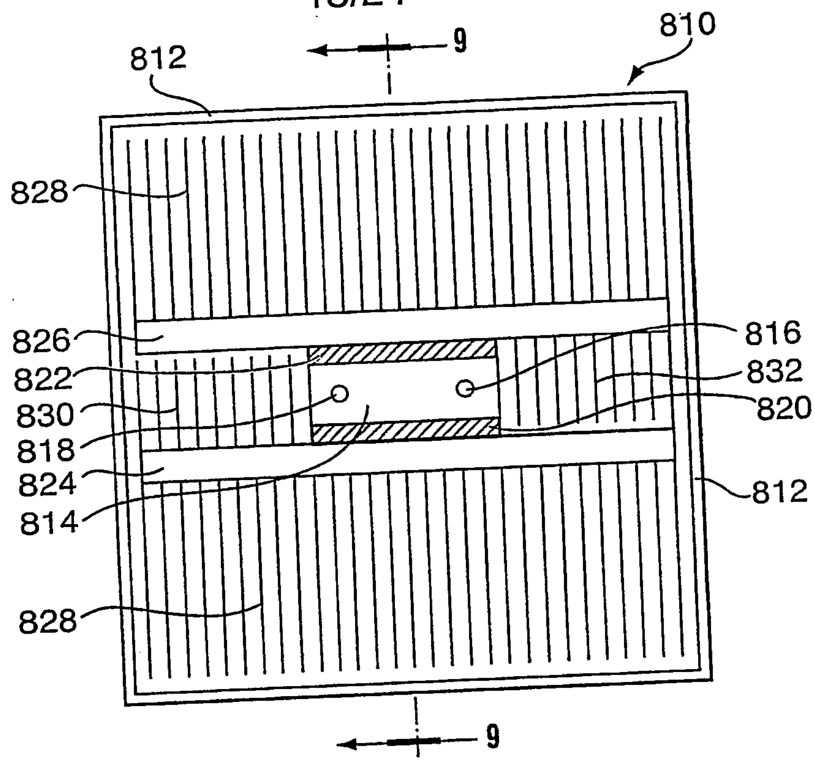

9
810
812
828
826
822
830
818
824
814
828
816
832
820
812
9

FIG. 9A

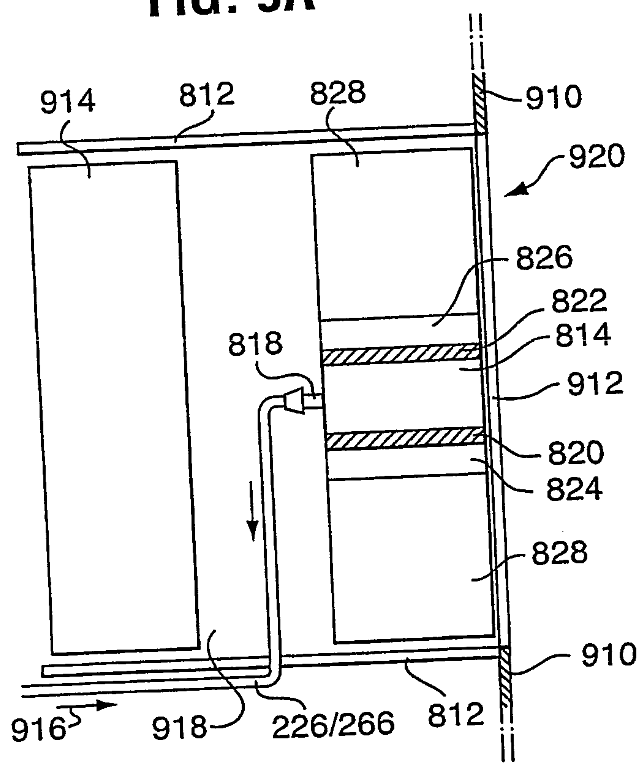

810
914
812
828
910
920
826
822
818
814
912
820
824
828
910
916
918
226/266
812

FIG. 9B

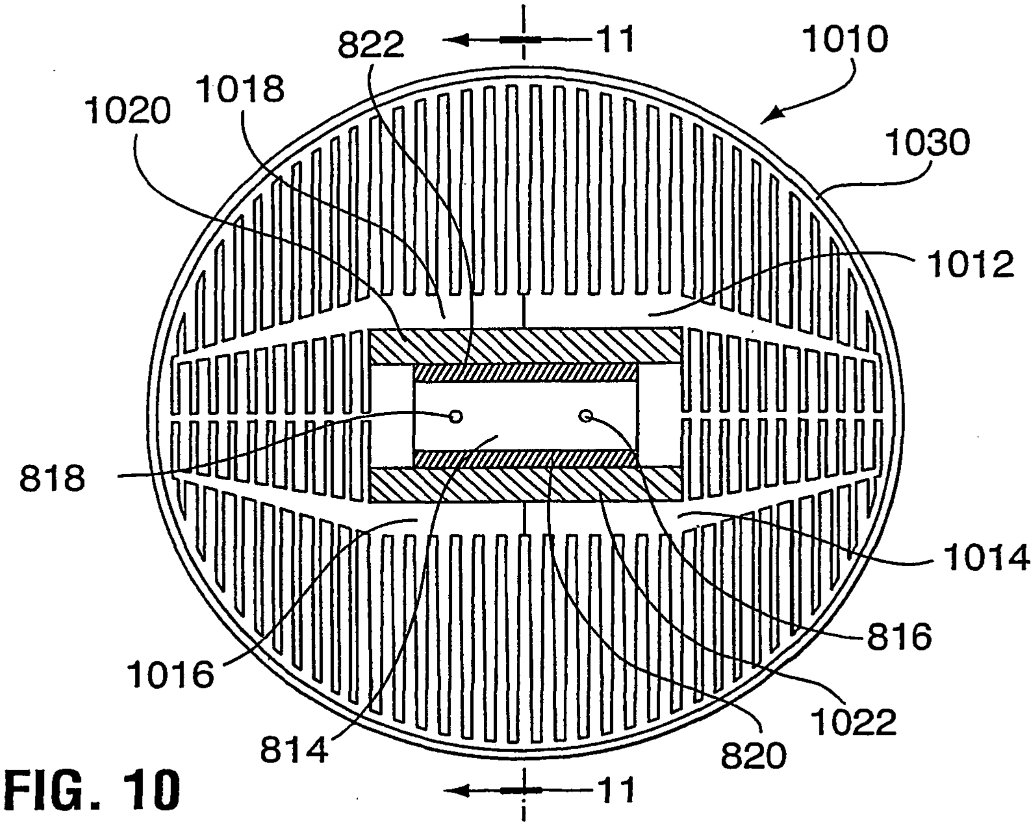


FIG. 10

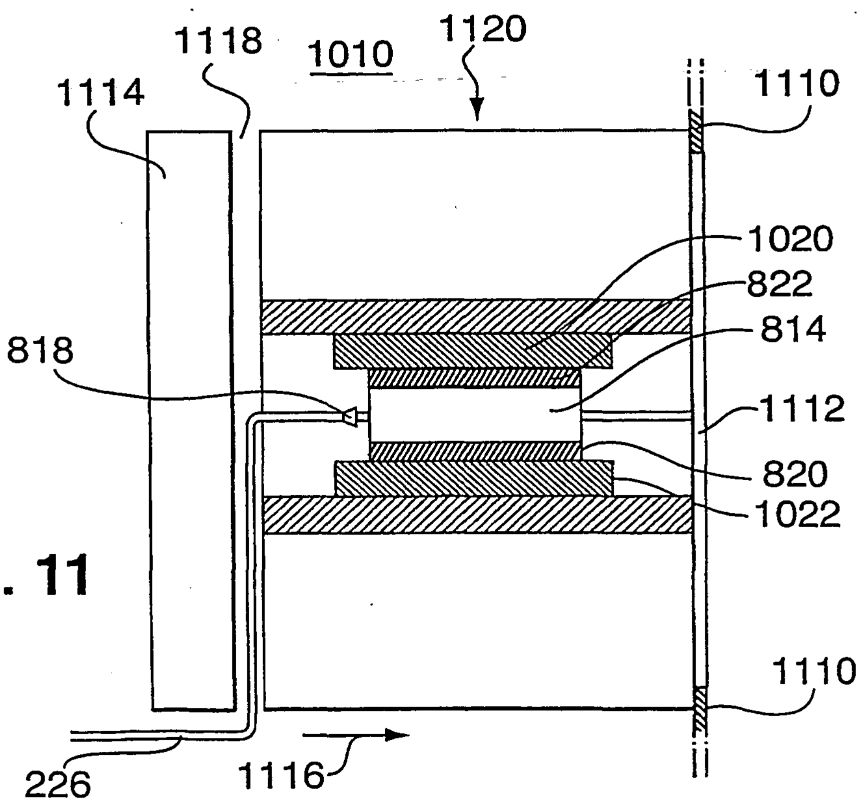


FIG. 11

BNSDOCID: <WO 03007372A2 I >

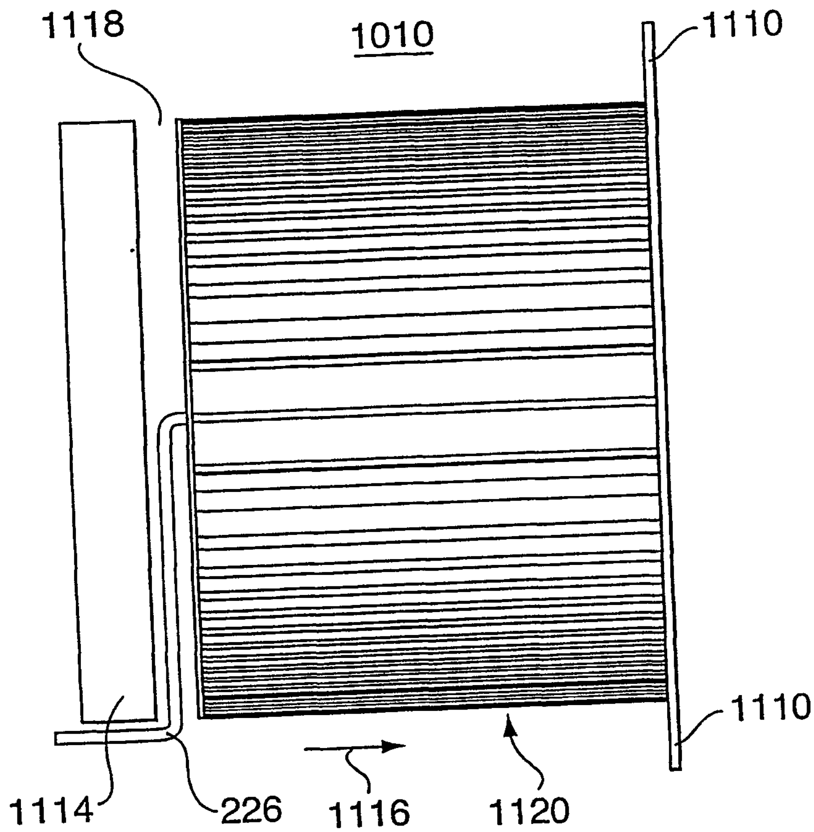


FIG. 12

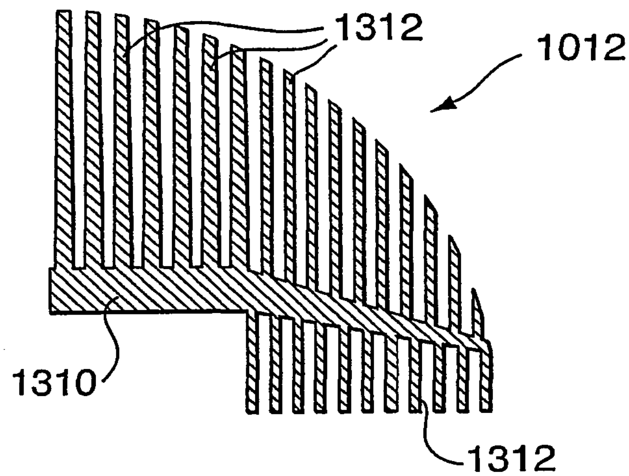


FIG. 13

BNSDOCID: <WO 03007372A2 I >

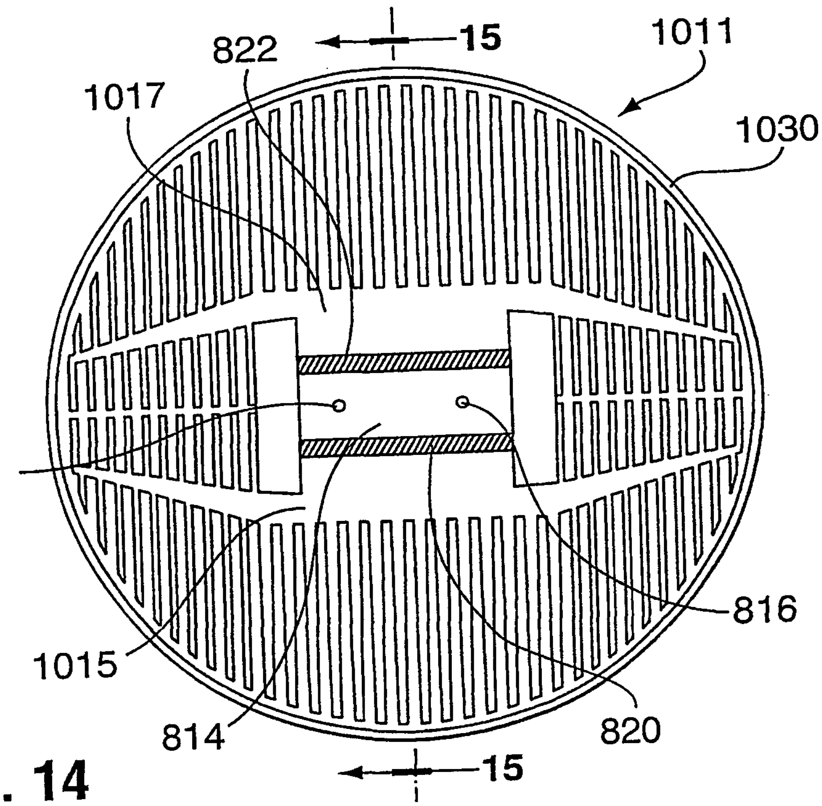

15
1011
822
1017
1030
818
816
1015
814
820
15

FIG. 14

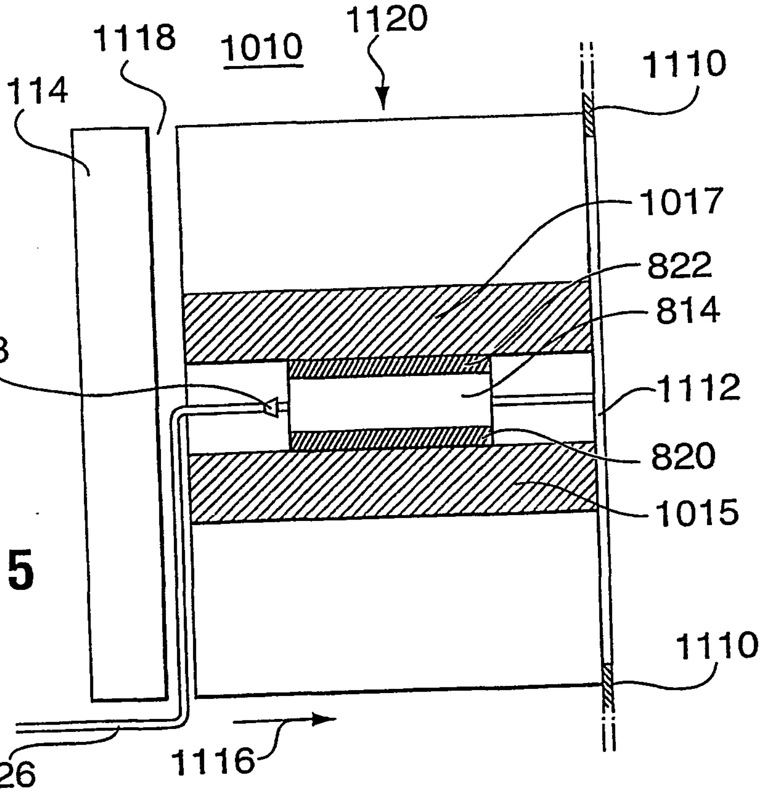

1118
1010
1120
1110
1114
1017
822
814
818
1112
820
1015
1110
226
1116

FIG. 15

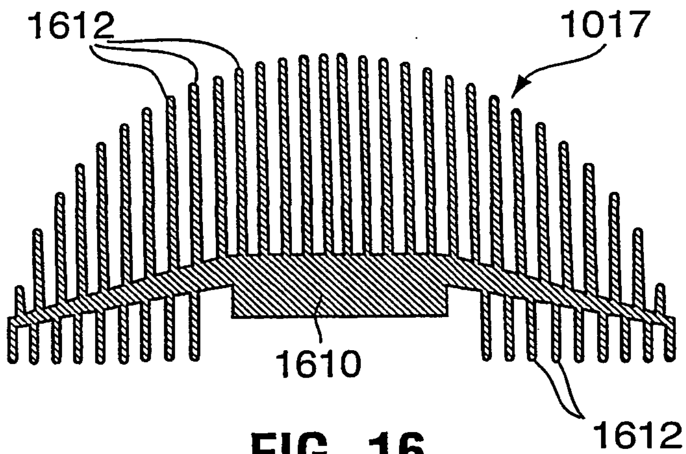


FIG. 16

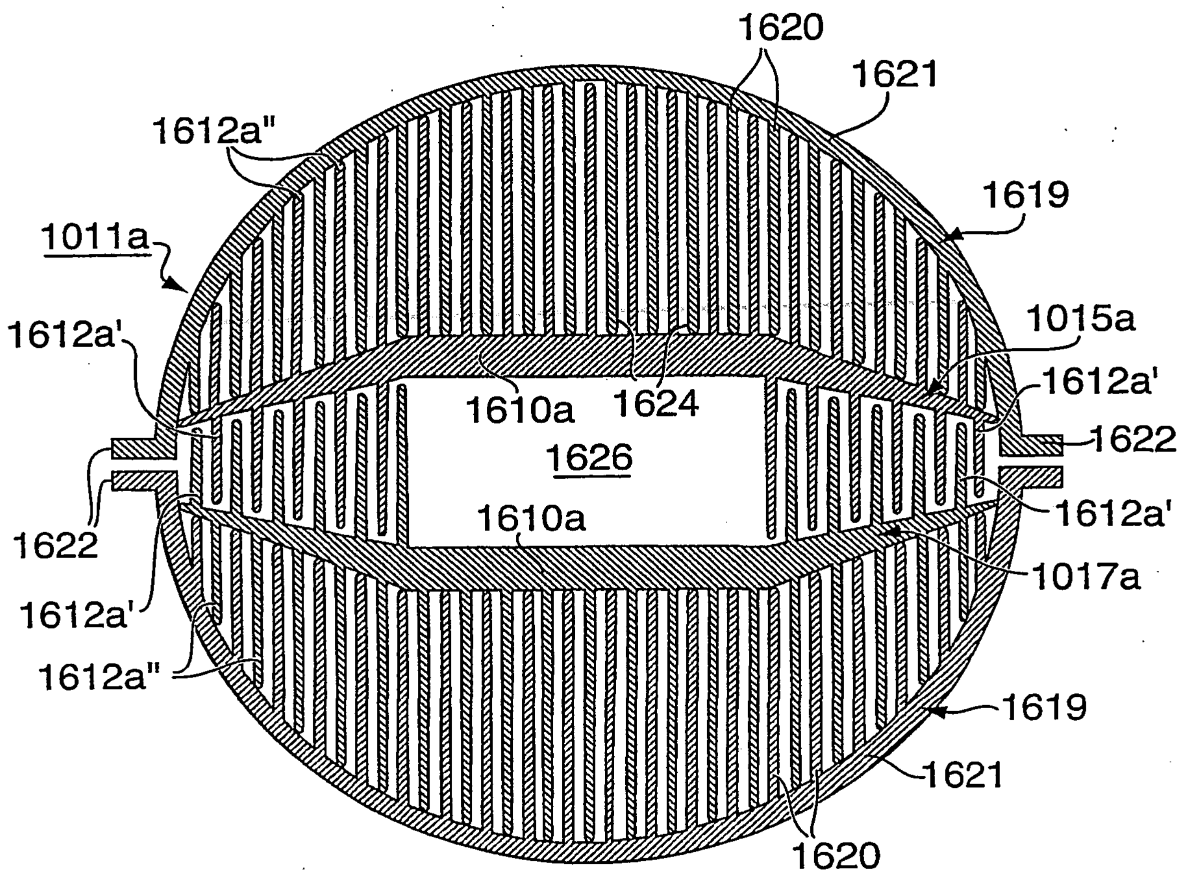


FIG. 17

BNSDOCID: <WO 03007372A2 I >

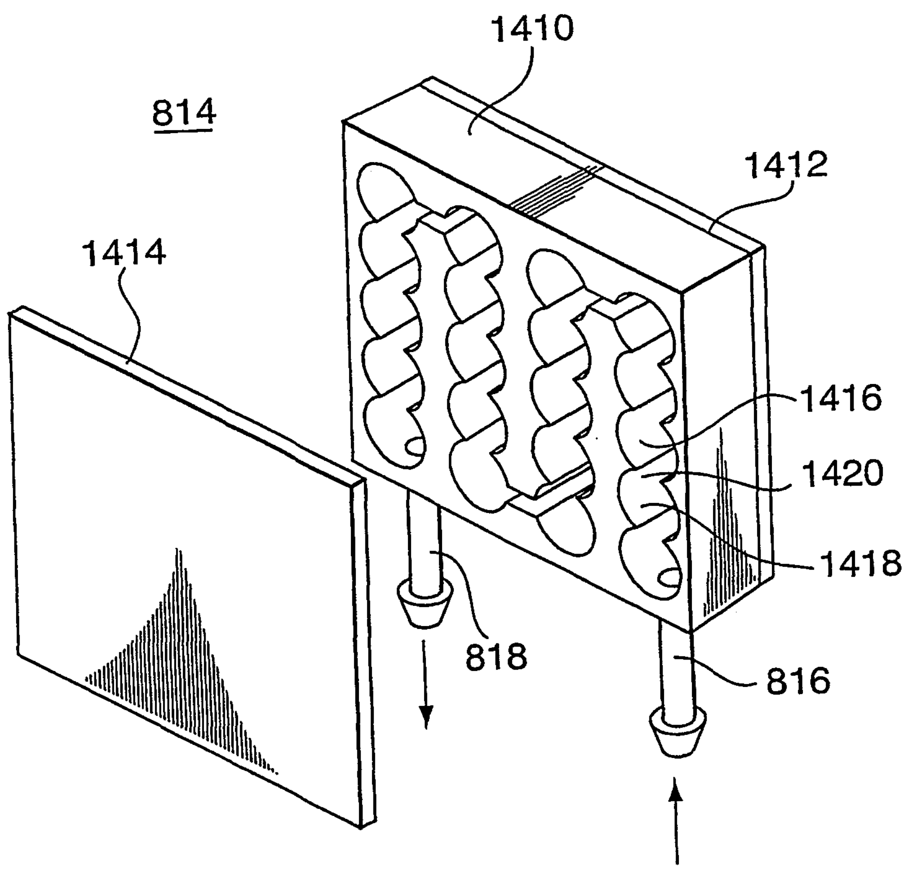


FIG.18

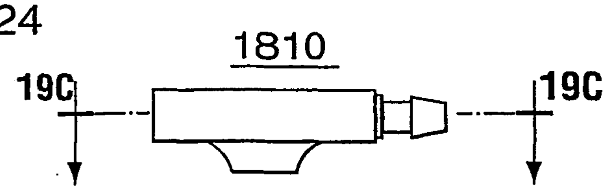


FIG. 19B

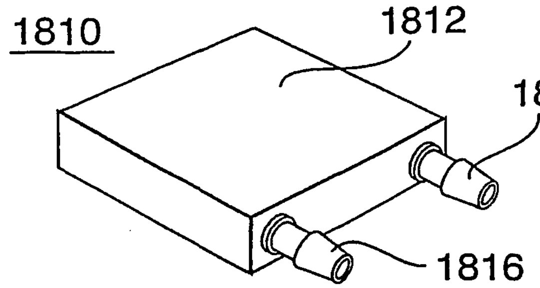
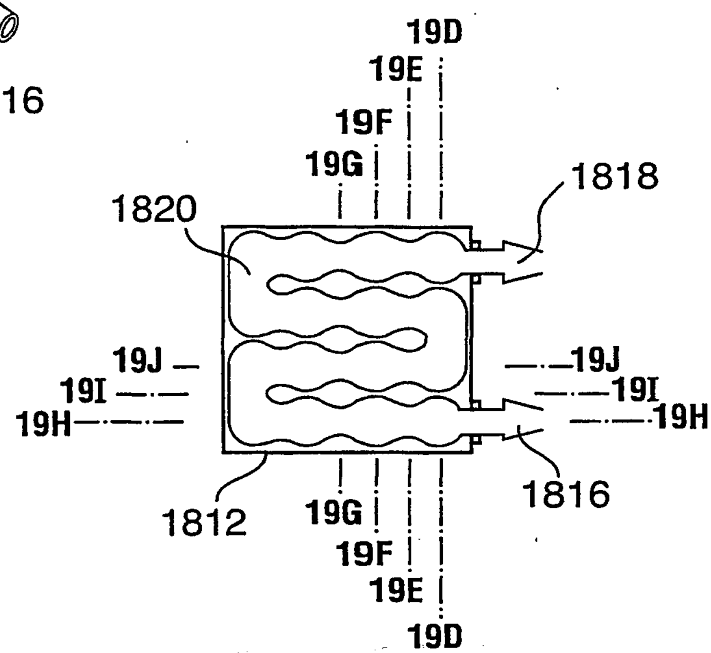


FIG.19A

FIG. 19C



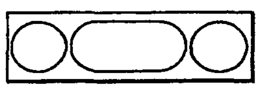


FIG. 19D

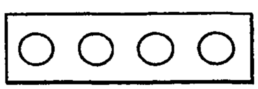


FIG. 19E

FIG. 19H

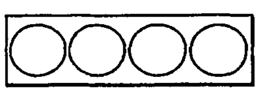


FIG. 19F

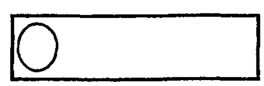


FIG. 19I

FIG. 19G

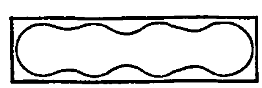


FIG. 19J

BNSDOCID: <WO 03007372A2 I >

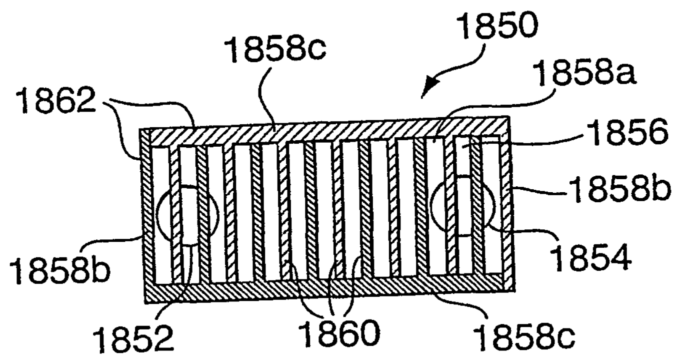


FIG. 20A

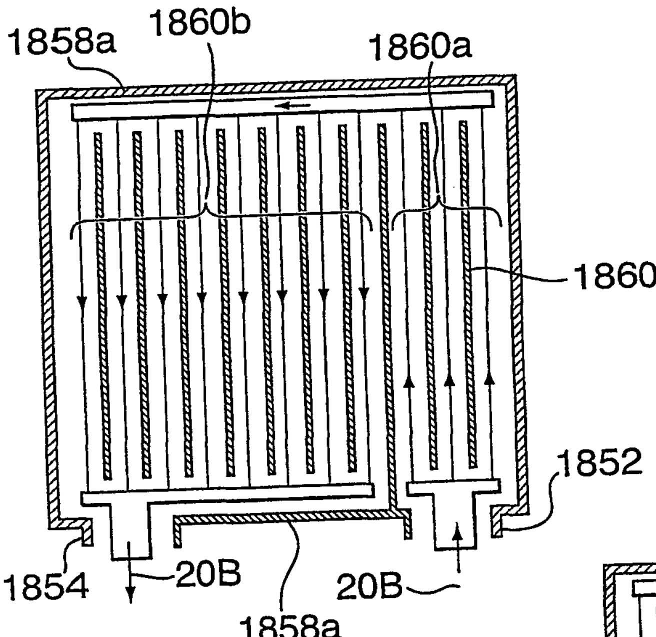


FIG. 20B

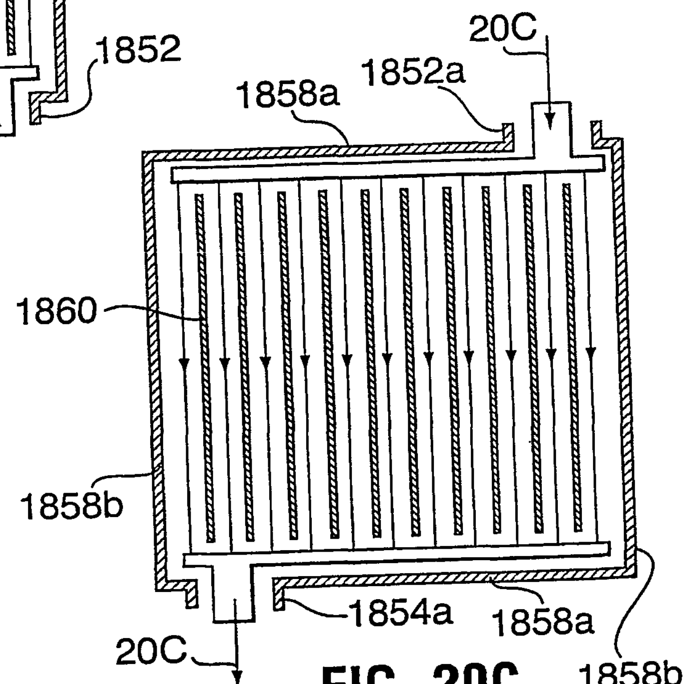


FIG. 20C

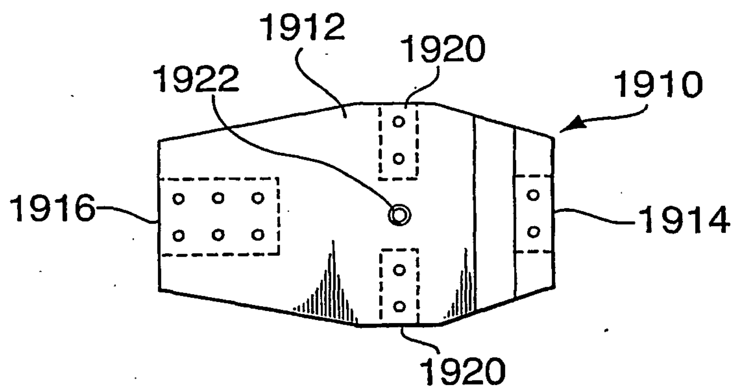


FIG. 21A

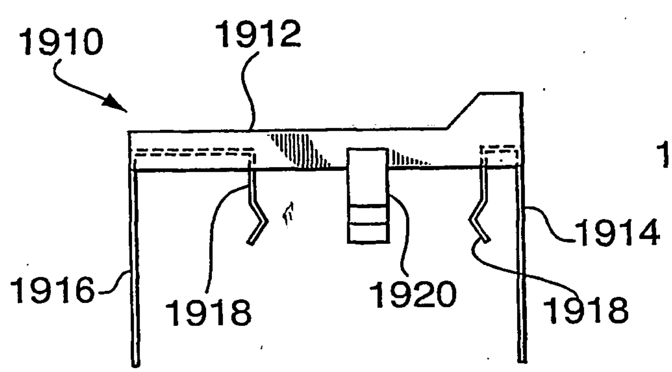


FIG. 21B

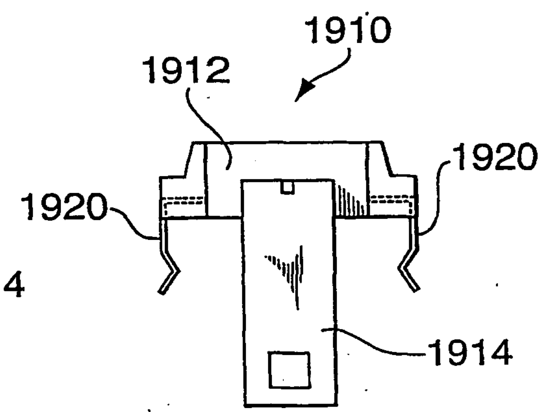


FIG. 21C

BNSDOCID: <WO 03007372A2 I >

THIS PAGE BLANK (USPTO)

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 January 2003 (23.01.2003)

PCT

(10) International Publication Number
WO 03/007372 A3

(51) International Patent Classification[7]: H01L 23/473, G06F 1/20, H05K 7/20

(21) International Application Number: PCT/CA02/01078

(22) International Filing Date: 15 July 2002 (15.07.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2,352,997 13 July 2001 (13.07.2001) CA
10/025,846 26 December 2001 (26.12.2001) US

(71) Applicant (*for all designated States except US*): **COOLIT SYSTEMS INC.** [CA/CA]; 10820 Hidden Valley Drive NW, Calgary, Alberta T3A 5H2 (CA).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **SCOTT, Alexander, Robin, Walter** [CA/CA]; 10820 Hidden Valley Drive NW, Calgary, Alberta T3A 5H2 (CA).

(74) Agent: **BENNETT JONES LLP**; Caldwell, Roseann, B., 4500 Bankers Hall East, 855 - 2nd Street SW, Calgary, Alberta T2P 4K7 (CA).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

(88) Date of publication of the international search report:
10 July 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 03/007372 A3

(54) Title: COOLING APPARATUS FOR ELECTRONIC DEVICES

(57) **Abstract:** An apparatus for cooling an electronic device that includes a fluid heat exchanger, a chiller, and a pump. The fluid heat exchanger transfers heat from a hot portion of the surface of the electronic device to a fluid and has a body through which the fluid may be circulated. The body has a protrusion having a first surface that may be thermally coupled to the hot portion such that the surface of the body is sufficiently distant from the surface of the electronic device that sufficient ambient air may circulate therebetween so as to substantially prevent condensation from forming on the surface of the electronic device and from forming on and dripping from the heat exchanger when the fluid is cooled to at least the dew point of the ambient air and circulated through the body. A heat-conducting path is provided from the first surface to a region of the body that is thermally coupled to the fluid when the fluid is circulated through the body. The chiller circulates the fluid through a chiller and the fluid heat exchanger.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 02/01078

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L23/473 G06F1/20 H05K7/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H05K G06F H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 126 919 A (YAMAMOTO ET AL.) 30 June 1992 (1992-06-30) column 4, line 36 -column 5, line 30; figures 1-3,12,17,18 ---	1,9-12, 24-27 4,5,13, 33-36
X A	US 4 712 158 A (KIKUCHI ET AL.) 8 December 1987 (1987-12-08) column 3, line 53 -column 5, line 39; figures 1-5 ---	1,9-13, 24-27 33-36,38
A	US 6 166 907 A (CHIEN) 26 December 2000 (2000-12-26) abstract column 2, line 40 - line 52; figures 1-4 ---	1,2,4,5, 9-13, 24-27, 33-35, 38,49, 50,60

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 March 2003	04/04/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Taylor, P

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 263 251 A (MATTHEWS) 23 November 1993 (1993-11-23) column 3, line 34 -column 5, line 23 column 6, line 26 -column 7, line 11; figures 1-7 -----	1,2,4,5, 9-13, 24-27, 33-35, 38,39

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 02/01078

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5126919 A	30-06-1992	JP 1720669 C	14-12-1992
		JP 4006099 B	04-02-1992
		JP 62282452 A	08-12-1987
		JP 1656400 C	13-04-1992
		JP 3015832 B	04-03-1991
		JP 62081098 A	14-04-1987
		JP 2017203 C	19-02-1996
		JP 7040380 B	01-05-1995
		JP 62119760 A	01-06-1987
		JP 1671087 C	12-06-1992
		JP 3034221 B	21-05-1991
		JP 62131546 A	13-06-1987
		JP 1671088 C	12-06-1992
		JP 3034222 B	21-05-1991
		JP 62131547 A	13-06-1987
		JP 1671089 C	12-06-1992
		JP 3034223 B	21-05-1991
		JP 62131548 A	13-06-1987
		JP 1671090 C	12-06-1992
		JP 3034224 B	21-05-1991
		JP 62131549 A	13-06-1987
		JP 1672529 C	12-06-1992
		JP 3034865 B	24-05-1991
		JP 62131551 A	13-06-1987
		JP 1672530 C	12-06-1992
		JP 3035832 B	29-05-1991
		JP 62131550 A	13-06-1987
		DE 3650709 D1	04-03-1999
		DE 3650709 T2	27-05-1999
		DE 3650719 D1	02-06-1999
		DE 3650719 T2	13-04-2000
		DE 3688962 D1	07-10-1993
		DE 3688962 T2	09-12-1993
		EP 0217676 A2	08-04-1987
		EP 0483107 A2	29-04-1992
		EP 0484320 A2	06-05-1992
		US 4783721 A	08-11-1988
		US 4879632 A	07-11-1989
		US 4920574 A	24-04-1990
		DE 3650687 D1	30-07-1998
		DE 3650687 T2	29-10-1998
		EP 0483108 A2	29-04-1992
		DE 3639397 A1	21-05-1987
		GB 2183413 A ,B	03-06-1987
		US 4797331 A	10-01-1989
US 4712158 A	08-12-1987	JP 1664258 C	19-05-1992
		JP 3029312 B	23-04-1991
		JP 61222242 A	02-10-1986
		AU 568973 B2	14-01-1988
		AU 5501586 A	02-10-1986
		BR 8601366 A	02-12-1986
		DE 3663614 D1	29-06-1989
		EP 0196863 A1	08-10-1986
		KR 9005447 B1	30-07-1990
US 6166907 A	26-12-2000	NONE	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 02/01078

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5263251 A	23-11-1993	US 5125451 A	30-06-1992
		US 5274920 A	04-01-1994
		AU 1756692 A	02-11-1992
		DE 4290875 T0	13-01-1994
		GB 2275575 A ,B	31-08-1994
		JP 6508911 T	06-10-1994
		WO 9217745 A1	15-10-1992
		US 5232047 A	03-08-1993

Form PCT/ISA/210 (patent family annex) (July 1992)

BNSDOCID: <WO 03007372A3 I >